XL. *Observations upon the Effects of Lightning, with an Account of the Apparatus proposed to prevent its Mischiefs to Buildings, more particularly to Powder Magazines; being Answers to certain Questions proposed by* M. Calandrini, *of* Geneva, *to* William Watson, *M. D. F. R. S.*

To the Right Honourable the Earl of MORTON, *President of the Royal Society.*

My Lord,

Read June 28, 1764. I Very lately received a letter from the learned and ingenious Monsieur Calandrini, of Geneva, who has a considerable employment in the Ordnance in that city. In this letter Monsieur Calandrini tells me, that he had perused with attention a letter which I wrote to the late Lord Anson, which contained some suggestions tending, as I hoped, to prevent the mischiefs occasioned by lightning to ships at sea; and which likewise might, on the same account, be useful to powder magazines. This letter was printed in the Philosophical Transactions *. He says, that he has considered with satisfaction the real advantages, which may arise from thence to fortified towns, where the quantity of gun-powder may, from any accident, endanger the whole fabric of a city.

This gentleman therefore is desirous of presenting a memorial to the Board of ordnance at Geneva; in which he would be very glad to explain to their satisfaction the method I propose. He has therefore

* Phil. Trans. Vol. LII. page 629.

ſent me the following queſtions, which he thinks tend to throw further light upon this ſubject, and has deſired my opinion upon them. As theſe may poſſibly hereafter be of public utility, I have taken the liberty of communicating them to your Lordſhip.

I. What ſort of apparatus is uſed at Philadelphia?

II. Whether there is not ſome improvement to be made to their methods?

III. In what manner this apparatus may be adapted to powder magazines?

IV. Into what place the thunder may be conducted, where there is no river near, to anſwer the purpoſe of the ſea about ſhips?

V. Whether the apparatus might not electrify the air, ſo as to occaſion lightning, which was, he believes, the cauſe of the death of Profeſſor Richmann of Peterſburg? This apparatus may not be dangerous to dwelling houſes, where the fire may ſlip without any manner of riſk; but may be attended with the moſt dreadful conſequences to a powder magazine, where the ſmalleſt ſpark may occaſion the exploſion of the whole.

VI. Whether the ſquare, or the circular form of building, will be eaſieſt adapted to the apparatus?

VII. Whether an iron bar fixed on the top of the building, to ſupport a weather-cock, may not attract the thunder bolt, and be conſequently dangerous to all buildings; but more eſpecially to powder magazines?

VIII. Whether there is not ſome particular manner of buildings, invented of late, adapted to powder magazines; either to diminiſh the ſhock of the exploſion, or to ſecure them againſt any accident, by the method uſed at Philadelphia?

Mr.

M. Calandrini ſays further, that he himſelf has been eye-witneſs of the effects of lightning coming into a room, which had received much damage from it. That he looked for the place it went out at, and after long ſearch perceived that it had followed the wire of the bell, which had conducted it through a very inconſiderable hole into the next room; from whence it had opened itſelf a paſſage into a back yard. This accident was at that time thought very extraordinary, being anterior to Dr. Franklin's experiment.

To M. Calandrini's queſtions I have ſent the following anſwers.

I. The apparatus, uſed at Philadelphia, conſiſts either of a long iron rod, placed upon the higheſt part of an houſe, or other building; or, of a ſhorter rod, inſerted into a long wooden pole, placed in the ſame manner. The iron rod, mentioned by Mr. Kinnerſley in the Philoſophical * Tranſactions, and which probably preſerved the houſe in Philadelphia upon which it was placed, extended in height about nine feet and a half above a ſtack of chimnies, to which it was fixed; but he ſuppoſes that three or four would have been ſufficient. Theſe rods are pointed at their upper extremity. It is indifferent, which of theſe two are uſed, provided that they are of height enough to reach above the chimnies, or any other part of the edifice. Connected to, or ſuſpended from, the metal of theſe, a metallic wire, generally of iron, is conducted, in the eaſieſt and moſt convenient manner, to the neareſt water, viz. to the well of the houſe, or any other water in the neighbourhood.

* Vol. LIII. page 95.

II. This method, wherever it has been employed, has hitherto perfectly anſwered the intention; no houſe in Philadelphia, or in any other place I have heard of, having ſuffered from the effects of lightning, where this apparatus has been erected. The improvements I ſhould recommend would be, firſt; that, as iron wire ſoon becomes ruſty, and when ruſty to the center is unfit for the preſent purpoſe; and as braſs wire is, when long expoſed to the weather, exceedingly brittle and liable to ſnap aſunder, the wire ſhould be of copper; and of a ſize not leſs than that of a large gooſe quill. Secondly, I prefer it's being conducted, from the rod at the top to the water below, on the outſide of the building, and thereby prevent the lightning from coming within the building. On houſes, where there are gutters and ſpouts of lead to carry off the rain, the wire need only be conducted to the lead of the gutters; and attention be had that the gutters and the ſpouts coming from them are in their whole length in contact, or very nearly ſo, one with the other. If the leaden ſpouts do not reach to the bottom of the building, a ſlip of lead, ſuch as is employed for the gutters, and about an inch wide, ſhould be faſtened to the bottom of one or two of the ſpouts, and conducted to the water. If a ſlip of lead, ſuch a one as has juſt been mentioned, was to be conducted from the rod at top to the gutters, it might with equal advantage be ſubſtituted for the copper wire; or further, a ſlip of lead of this kind may be connected with the rod at the top of the houſe; and, where there are no leaden gutters or ſpouts, may be conducted on the outſide of the houſe down to the water, as I before mentioned.

oned. I would recommend likewiſe an increaſe of their number; as the effects of one apparatus of this kind can extend only to a certain diſtance, and that to no great one; and the ſecurity, where miſchiefs from lightning are frequent, muſt ariſe from their number. In countries and places ſo circumſtanced, no houſe or other building ſhould be without one at leaſt; large edifices ought to have ſeveral. The number ſhould be in proportion to the ſize of the building.

III. In powder magazines, I ſhould recommend the apparatus to be detached from the building itſelf; and to be only placed as near it as might be. Powder magazines ſhould never be conſtructed ſo, as to cover a large quantity of ground. If ſecurity from lightning was conſidered in their conſtruction as a conſiderable object, I ſhould recommend a circular building; in the periphery of which ſhould be placed ſtorehouſes ſufficient in their number and extent to contain the quantity of powder propoſed. In the centre of this circle ſhould be a well, very near which ſhould be erected a pole or maſt, high enough to reach ſome feet above the buildings of the powder magazine, or the buildings in it's neighbourhood. From this maſt there ſhould riſe a braſs rod, five or ſix feet in length, an inch in thickneſs, and ending in a point; and from this rod a wire of copper of a ſize not leſs than that of a large gooſe quill, ſhould be conveyed down the maſt, and terminate in the water of the well. If there is no well, the wire ſhould be laid into the neareſt water; as the expence even of ſome hundred yards of a wire of this ſort can hardly be conſidered as an object in an affair of this importance.

tance. For though I have reaſon to believe, that the wire communicating with the ground would prevent the miſchiefs of a thunder cloud, which came near an apparatus of this ſort; yet as water is a more ready conductor than the ground, it ſhould, if poſſible, be inſiſted upon in this particular caſe, and employed. Mr. Weſt's apparatus, deſcribed by the before-mentioned Mr. Kinnerſley, terminated in an iron ſtake, driven four or five feet into the ground; nevertheleſs the earth did not conduct the lightning ſo faſt but that, in a thunder ſtorm, the lightning was ſeen to be diffuſed near the ſtake two or three yards over the pavement, though at that time very wet with rain. It is preſumed, that had this iron ſtake been placed in water inſtead of earth, the lightning had not been viſible, on account of the water's receiving the electric matter more readily than earth. Where this apparatus therefore is applied to powder magazines, it ſhould certainly terminate in water. At Mr. Hamilton's at Cobham, about twenty miles from hence, where an apparatus of this ſort was erected upon an high and greatly-expoſed building, as there was no water but at a great diſtance, the bottom of the wire was placed deep in an hill of moiſt ſand. If, inſtead of one wire, two, three, or more, were adapted to the braſs rod in this manner, and conducted to the water, or if the braſs rod itſelf was continued to the water, I ſhould conſider it, in extraordinary caſes, as an additional ſecurity. This will explain my ſentiments upon the third, fourth, and ſixth queſtions.

V. As the expectation of the utility of this apparatus is preſumed to be the preventing of the accumulation of electricity in its neighbourhood, by affording

ing a conſtant and eaſy paſſage to the electricity of the clouds ſurcharged therewith, nothing, in my opinion, need be apprehended from the apparatus electrifying the air; as its principal operation is conceived to be the reverſe of that, viz. diveſting the air of it's electricity. I am well apprized from experiments made here, that the earth is frequently electrified *plus*, and the clouds *minus*; and that this change of *plus* and *minus* between the clouds and earth are ſometimes ſeen to vary ſeveral times in a quarter of an hour: but in that caſe it is preſumed, that the clouds, within the ſphere of action of the apparatus, have by it's operation their electricity brought to the ſame ſtandard with that of the earth in its neighbourhood, and *vice verſâ*; and conſequently, that the miſchiefs which might ariſe from the difference of the denſities of the electricity in the earth and clouds are prevented, by the equilibrium between them being maintained. This ſubject, in relation to the electricity's being *plus* or *minus*, I many years ago conſidered, and laid my thoughts thereupon before the public, as may be ſeen in the Philoſophical Tranſactions, Vol. XLV.

That the atmoſphere at times is very ſtrongly electrified, is evident, to ſay nothing of lightning, not only from our apparatus, but from the maſts of ſhips, being beſet with *St. Elmo's fires*, which I believe would ſcarce, if ever, happen, were the maſts provided with an apparatus of this ſort; unleſs the cauſe might be ſo great, and come on ſo faſt, that the metal employed between the tops of the maſts and the water might not, on account of the vaſtneſs of the cauſe, be large enough for the purpoſe. If it ſhould ſo happen, *St. Elmo's fires* might ſtill appear

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at the tops of the maſts, and thunder clouds might burſt near them, and exert their dreadful effects *. That even artificial electricity, when in too great a quantity, and hurried on too faſt through a fine iron wire has a remarkable effect upon the wire, appears from a very curious experiment of Mr. Kinnerſley of Penſylvania. This gentleman in the preſence of Dr. Franklin, by *his caſe of bottles* being electrified fully, and made to explode at once, after the manner of the experiment of Leyden, through a fine iron wire, the wire appeared at firſt red hot, and then fell into drops, which burned themſelves into the ſurface of his table or floor. Theſe drops cool in a ſpherical figure, like very ſmall ſhot, of which Dr. Franklin tranſmitted ſome hither to Mr. Canton †, who has repeated this experiment. This proves the fuſion to have been very compleat, as nothing leſs than the moſt perfect fluidity could give this figure to melted iron. Theſe effects from artificial lightning, are exactly ſimilar to thoſe of the natural; as we have ſeveral times known iron wires,

* See more upon this ſubject Phil. Tranſ. Vol. XLVIII. page 215.

† The diameter of a piece of Mr. Kinnerſley's wire, which I received from Doctor Franklin, was one part in 182 of an inch. Artificial lightning from a caſe of 35 bottles, I find will entirely deſtroy braſs wire of one part in 330 of an inch. At the time of the ſtroke, a great number of ſparks, like thoſe from a flint and ſteel, fly upwards, and laterally from the place where the wire was laid, and loſe their light in the daytime at the diſtance of about two or three inches. After the exploſion, a mark appears on the table the whole length of the wire; and ſome very ſmall round particles of braſs may be diſcovered, by a magnifier, near the mark; but no part of the wire itſelf can be found. J. CANTON.

nails,

nails, and other metallic ſubſtances to have been melted, and parts of them, while hot, bedding themſelves in wood, by a thunder ſtorm. Of this we had ſome inſtances here in a thunder ſtorm, which happened in July 1759, of which the effects were communicated to the public in the * Philoſophical Tranſactions. As metal has been made red hot, and melted by artificial lightning, how much greater muſt be preſumed to be the effects of the natural; and how much larger ought to be the metallic part of the apparatus, to avert its miſchief? This requires particular attention.

VII. I was of opinion, that iron bars to ſupport weather cocks, if they were placed upon the tops of buildings made of brick or ſtone, and in contact with either of theſe materials, were not dangerous to ordinary buildings on the account you mention, except in very particular and extraordinary caſes; as theſe ſubſtances, when not much heated, conduct the electric matter in a very conſiderable degree. But what lately happened to St. Bride's Steeple, as well as the miſchief to South-Weald church on the ſame day, evinces, to me at leaſt, that the apparatus, uſually applied to weather cocks, ſhould never be truſted in any building, without a metallic communication from them to ſome water, or at leaſt very moiſt ground. St. Bride's Steeple, one of the moſt beautiful in London, was, on Monday, June 18, about ten minutes before three in the afternoon, very greatly injured, in one of the moſt ſevere thunder ſtorms, which ever happened here.

From as attentive an examination, as the ſteeple at the preſent will admit of without ſcaffolding, it

* See Volume LI.

appears to me, that the weather-cock and its apparatus had the principal ſhare in occaſioning the great miſchief done to the upper part of the ſteeple. I am of opinion, that the lightning firſt took the weather-cock and was conducted, without injuring the metal or any thing elſe, as low as where the large iron bar or ſpindle, which is inſerted into the top of the ſteeple, and comes down ſeveral feet of its length, terminates. There the metallic communication ceaſing, part of the lightning exploded, cracked and ſhattered the obeliſk, which terminates the ſpire of the ſteeple, in its whole diameter, and threw off at this place ſeveral large peices of Portland ſtone, of which this ſteeple is built. Here it likewiſe removed a ſtone from its place, but not far enough to be thrown down. From hence the lightning ſeems to have ruſhed upon two horizontal iron bars, which are placed within the building, croſs each other, to give additional ſtrength to the obeliſk, almoſt at the baſe thereof, and not much above the upper ſtory: here, on the North Eaſt and Eaſt ſide, it exploded again at the end of the iron bar, and threw off a conſiderable quantity of ſtone. And here, for the ſake of explanation, I muſt obſerve, that the ſpire of this ſteeple, where it riſes above the bell tower, is compoſed of four ſtories, beſides the obeliſk placed over them. The loweſt and ſecond are of the Tuſcan order; the third is Ionic; and the fourth or uppermoſt Compoſite or Roman. The ſtone piers of theſe ſtories are connected together and ſtrengthened by iron bars placed horizontally near the height of the capitals of the pilaſters, and each ſtory has only one ſet of theſe bars. From the croſs bars near the baſe

of

of the obeliſk juſt now mentioned, the lightning broke through the roof above the Compoſite ſtory; at the ends of another ſet of iron bars placed lower than the former, from which it tore out a large portion of the ſtone. It then ſtruck the iron bars of this ſtory, which are placed immediately under, and in contact with the ſtones, broke one of the iron bars directly acroſs, and bent the larger part of it from its horizontal direction to near an angle of 45°. Its rapid progreſs being here in ſome meaſure prevented, at the end of one of the iron bars, it threw off the upper part of one of the Compoſite pillars juſt above its capital and a large portion of the cornice projecting over it, and that with ſuch a force, that part of a ſtone which was placed here and formed a portion of the cornice, and weighed ſeventy two pounds, was projected, not only the whole length of the body of the church, but beyond it, acroſs St. Bride's Lane; where it fell upon the top of an houſe, and broke through the roof and lodged in the garret. The horizontal diſtance from the ſteeple to the place where it fell, was at leaſt 150 feet; the heigth, from which it fell, ſomewhat more than two hundred. This piece of ſtone was of a very irregular figure, and muſt have required an amazing force to rend it, detach it from the building, and throw it to ſuch a diſtance. The ſhaft of the pillar, the next to the Eaſt of that whoſe upper part had ſuffered ſo much, was likewiſe violently ſtruck; and a large portion of its diameter broke out and thrown down. The Ionic ſtory has ſuffered conſiderably, more particularly the pilaſter fronting the North Eaſt, and placed directly under the Compoſite column, whoſe top was

thrown off. This pilaſter is much injured, but the ſtory in general has ſuffered leſs than the Compoſite, and that chiefly where the irons are inſerted; the upper Tuſcan leſs than that, and the lower Tuſcan but little, except in the North Eaſt pier, which is conſiderably cracked and ſhaken; as if in its paſſage part of the force of the lightning was ſpent in theſe exploſions, and part abſorbed and conducted by the maſſes of ſtone. The damage done to the ſteeple is, except near the top, confined almoſt to the Eaſt and North Eaſt ſide, and moſt generally where the ends of the iron bars have been inſerted into the ſtone or placed under it; and in ſome places, by its violence in the ſtone, its paſſage may be traced from one iron bar to another. And it is very remarkable, that, to leſſen the quantity of ſtone in this beautiful ſteeple, in ſeveral parts, cramps of iron have been employed; and upon theſe, ſtones of no great thickneſs have been placed, both by way of ornament and to cover the cramped joint. In ſeveral places, theſe ſquare ſtones have, on account of their covering the iron, been quite blown off, and thrown away. A great number of ſtones, ſome of them large ones, were thrown from the ſteeple, three of which fell upon the roof of the church, and did great damage to it; and one of theſe broke through the large timbers, which form it, and lodged in the gallery.

In the tower of the ſteeple, in the room where the bells are placed, the lightning took the South-weſt window above the bells and cloſe to the window, not far from an iron bar, which goes round, and rent out ſeveral large ſtones; ſome of which fell into the bell, which was very near this part of the ſteeple, and

and was the largeſt in the ſteeple; and, paſſing below the bell, tore out at another place, in a line with the former, a great number more. One of the ſtones, torn out above the bell, was thrown to the North-eaſt ſide of the tower. Between the two places, in which the lightning had here exerted its fury, the wooden block, which confined the axis of the frame of the great bell, and was faſtened down with two iron ſtaples, was thrown off, and the ſtaples torn out. No damage at preſent ſeems done to the bell.

It is remarkable, that, leſs than twenty years ago, one of the ſtones of the obeliſk of this ſteeple was obſerved to be moved from its place, and project ſome inches over thoſe under it. This ſtone was about ſeven feet from the top of the obeliſk. Danger being apprehended from this ſtate of the ſpire, it was taken down to the place where the ſtone was removed, and rebuilt with new ſtone. This accident, at that time, was ſuppoſed to be owing to the ringing of the bells; but it is highly probable, from what has lately happened, that, as that ſtone was removed from its place, very near to that part of the ſpire, where it is now cracked and ſhivered quite a croſs and ſeveral pieces of ſtone thrown down, it was owing to the ſame cauſe as the preſent damage, viz. lightning, though not at that time adverted to.

The lightning on June 18 came from the Weſt and South-weſt; the damage done both to St. Bride's church and South Weald was on the Eaſt and North Eaſt ſides, except that in the bell-loft at St. Bride's. The ſtones both from the ſteeple of St. Bride's and in its tower were thrown to the Eaſt and North Eaſt.

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Since the communication of this paper to the Royal Society, the ſteeple of St. Bride's has been ſurveyed, and found ſo very much damaged in ſeveral of its parts, that eighty five feet have been taken down, in order to reſtore it ſubſtantially. Within theſe eighty five feet are comprehended the obeliſk, placed at the top of the ſteeple, the ſmall dome immediatly under it, the ſpace between that and the uppermoſt or Compoſite ſtory, the Compoſite ſtory, and the Ionic ſtory. This laſt, on the Eaſt and North ſides, was taken down to its bottom; but on the other ſides, as they were not injured, ſome parts were permitted to ſtand. Three piers were likewiſe taken down of the ſecond Tuſcan ſtory, and one pier of the firſt. The ſcaffolding to take this down and rebuild it enabled me minutely to examine, not only the damages occaſioned by the lightning, but the manner of its progreſs. This examination confirmed the opinion of the cauſe and manner of this accident, which I communicated to the Royal Society, ſoon after it happened; and before a near inſpection could be obtained. It compleatly indicated the great danger of inſulated maſſes of metal to buildings from lightning; and, on the contrary, evinced the utility and importance of maſſes of metal continued, and properly conducted, in defending them from its direful effects. The iron and lead employed in this ſteeple in order to ſtrengthen and preſerve it, did almoſt occaſion its deſtruction: though after it was ſtruck by the lightening, had it not been for theſe materials keeping the remaining parts together, a great part of the ſteeple muſt have fallen.

The operation and progreſs of the lightning in the obeliſk and upper parts of the ſteeple deſerve more particular attention. To form a more perfect idea of theſe, the following meaſures will in ſome degree contribute.

	Feet	Inches.	
The height of the octogonal obeliſk - - - - - - - - - - -	22	- - 3	
Length of the iron ſpindle - -	19	- - 9	
Thickneſs of the ſpindle, where inſerted into the ſtone. - - -	0	- - 2	ſquare
Its length inſerted into the ſtone	9	- - 10	
From the bottom of the ſpindle to the firſt cramped joints. - -	5	- - 10	
Three courſes of ſtones without cramps. - - - - - - - - - -	5	- - 7	
From the bottom of the ſpindle to the firſt concealed chain. - -	11	- - 5	
From the firſt concealed chain one foot above the baſe of the obeliſk to the firſt croſs chain. - -	2	- - 0	
From the firſt croſs chain to the ſecond, placed in the dome -	8	- - 10	

The vane, the croſs above it, the ball and its ſocket, which covered ſo much of the ſpindle as aroſe above the ſtone, to near ten feet of its length, were of copper gilt. This length of the ſpindle was cylindrical, but the other part was made ſquare, where it began to be inſerted into the ſtone. To faſten this ſpindle more ſecurely in the courſes of ſtone, melted lead had been poured. This lead, in the two lower courſes of ſtone through which the ſpindle had paſſed, not only filled all the ſpace left between the ſpindle and the ſtones,

ſtones; but had, as it were, ramified itſelf not only between the joints of the ſtones, but had inſinuated itſelf in its melted ſtate into all their ſmall clefts and interſtices. The ſpindle terminated in one ſtone, which occupied the whole area of the obeliſk, and was three feet and near two inches in diameter, and one foot in thickneſs. Into this ſtone the ſpindle was inſerted five inches of its depth, and faſtened by melted lead. Under this ſtone the obeliſk was hollow; but above it was ſolid, excepting the ſpace left for the ſpindle.

Upon examining theſe ſeveral particulars, no injury had been done by the lightening to the vane, its croſs, copper ball, or ſpindle. Of the ſeven courſes of ſtone at the upper part of the obeliſk, and which were above the whole ſtone into which the ſpindle was inſerted, the five upper courſes, though connected together at top and bottom with iron collars ſodered with lead, were not damaged; but the two ſtones, which formed the ſixth courſe, were cracked, ſhivered, and fragments thrown from them. The ſeventh courſe conſiſted likewiſe of two ſolid ſtones. Theſe were burſt from the ſpindle, which was, by the intervention of the lead, connected with them, broke into many parts; each was moved from its place; ſome pieces were thrown down, and one large one projected five inches over the ſtone, immediately under it. The whole ſtone, into which the ſpindle was inſerted, and upon which it reſted, was burſt from the center into a great many pieces, and every piece removed from its place. Some of theſe were thrown from the ſteeple. Several of the larger maſſes of this ſtone, which ſtill cohered, were very much ſhivered. The center of the ſtone,

upon

and near which the ſpindle reſted, was beaten to powder, and a hole made through the under part of the ſtone. That this ſtone in this condition ſhould ſtill ſupport the ſeven courſes above it, which weighed four tuns, excluſive of the ſpindle, vane, and their appertinances; and that the whole did not fall when ſtruck with the lightning, is in no ſmall degree ſurprizing.

From the bottom of the ſpindle to the firſt courſe of ſtone, where the workmen had uſed iron cramps, the diſtance was five feet ſeven inches. Theſe cramps were bedded in the ſtone. Part of the lightning, from the bottom of the ſpindle through the hole juſt now mentioned, ſeized theſe cramps, and threw off large ſcales of ſtones at their ends. From theſe there were three courſes of ſtone, in which there were no cramps; theſe ſuffered nothing.

In edifices of this kind, for additional ſtrength, the builders employ bars of iron, connected together in ſuch a manner as their exigencies require; and theſe, though they have no links, are denominated chains. Theſe are ſometimes ſo adapted to the courſes of ſtone as not to be viſible, and are perfectly concealed: at other times, they are in part viſible, and in part concealed.

The firſt metal, that occurred after the cramps before mentioned, was a concealed chain, one foot above the baſe of the obeliſk, and two feet above the firſt croſs chain. Here two ſtones were burſt and ſhattered. In the courſe of ſtone, where the firſt croſs chain was inſerted, and the ſeveral ſtones connected by iron cramps, many of the ſtones were much ſhattered.

At the baſe of the dome, near nine feet below the firſt croſs chain, was a ſecond. This chain was a double croſs connected at its ends with a circle of iron, which was bedded into the whole courſe and faſtened by melted lead. Here the lightning made great ravage, burſt and threw off the ſtones in which the iron circle was bedded, and tore out part of the roof of the dome, threw off two pieces of the cornice and one of the vaſes, which was contiguous to it. Theſe two pieces of cornice weighed twelve hundred pounds. The courſes of ſtone between the two chains, except thoſe I juſt now mentioned, were not injured.

To what is here ſaid, I ſhall only add, that in no part the ſteeple was injured, except where the ſtones were in contact or very near the iron and lead employed in its building; and the quantity of ſtone burſt, ſpoiled, or ſo much damaged as not fit to be uſed again, amounts, as I am informed by Mr. Stanes, a very honeſt and ingenious maſon, who has contracted to repair the damage done by the lightning, to not leſs than five and twenty tuns. An amazing quantity!

The above mentioned Mr. Stanes was employed, a few years ſince, in the repair of the ſteeple of St. Mary le Bow in Cheapſide, which was injured by a very rare and uncommon accident. At its erection, the builders had employed, near the top of the ſpire, for additional ſecurity, ſeveral iron cramps; the ends of which, by being expoſed to the weather, became ruſty, ſwelled, and ſo much enlarged thereby, as to raiſe the ſtones above them, and to deflect the top of the ſpire ſix inches from the perpendicular. Danger being apprehended from this ſituation, the ſpire was taken

taken down ſeveral feet of its length, and properly repaired. This ought to be a caution to ſucceeding builders, that if, in edifices of this kind, they find it expedient to employ cramps, they ſhould be either of copper, which is not liable to ſwell by moiſture; or, if iron be uſed, ſo much ſpace ſhould be left in the under bed of the ſtones, which immediately cover the cramps, that they may have room to extend themſelves without danger to the building. This remark, though not immediately relating to our preſent purpoſe, will not, I hope, be thought impertinent in this place.

But to return: this thunder ſtorm had been preceded by ſeveral very warm days. The nights had ſcarce furniſhed any dew: the air was quite dry, and in a ſtate perfectly unfit to part with its highly-accumulated electricity without violent efforts. This great dryneſs made the ſtones of St. Bride's ſteeple, and all other buildings under the like circumſtances, far leſs fit than if they had been in a moiſt ſtate, to conduct the lightning, and prevent the miſchief. For though this thunder ſtorm ended in a heavy ſhower of rain, none except a few very large drops fell till after the church was ſtruck; and I have no doubt, but that the ſucceeding rain prevented many accidents of a ſimilar kind, by bringing down with every drop of it part of the electric matter; and thereby reſtoring the equilibrium between the earth and clouds. It is frequently taken notice of, in attending to the apparatus for obſerving the electricity of the clouds, that tho' the ſky is much darkened, and there have been ſeveral claps of thunder at no great diſtance, yet the apparatus will be ſcarce affected by it; but as ſoon

as the rain begins, and falls upon ſo much of the apparatus, as is placed in the open air, the bells of the apparatus in the houſe ring, and the electrical ſnaps ſucceed each other in a very extraordinary manner. This demonſtrates, that every drop of rain brings down part of the electric matter of a thunder cloud, and diſſipates it in the earth and water; and prevents thereby the miſchiefs of its violent and ſudden exploſion. Hence, when the heavens have a menacing appearance, a ſhower of rain is much to be wiſhed for.

From theſe conſiderations, I have no doubt, but that the miſchief done to St. Bride's ſteeple was owing to the efforts of the lightning, after it had poſſeſſed the apparatus of the weathercock, endeavouring to force itſelf a paſſage from thence to the iron work, employed in the ſteeple. As this muſt be done *per ſaltum*, there being no regular metallic communication, it is no wonder, when its force is vehement, that it rends every thing which is not metallic, that obſtructs its eaſy paſſage; and in this particular inſtance, the ravages increaſed as the lightning to a certain diſtance came down the ſteeple. To procure this eaſy paſſage and avert the ravage occaſioned by the want of it, in future, as much as our preſent knowledge in theſe matters will enable us to do, I cannot ſufficiently recommend metallic communications between the metal at the top and water, either as has been before mentioned, or in any other convenient manner, taking care not to be too frugal of the metal employed. This was firſt ſuggeſted by that excellent Philoſopher Dr. Franklin; and ſince much uſed in Philadelphia, and other parts of North America.

Near

Near the ſame time, that the miſchief was done to St. Bride's church, the maſt of his Majeſty's ſhip Ramaillies, lying at Chatham, was ſplit and torn to pieces by the lightening. This is the leſs extraordinary, as, from its height, figure, and conſtituent parts, the maſt of a ſhip ſtops the progreſs of lightening much more than edifices of the ſame height, made of brick or ſtone. This therefore ſeems to require particular attention; but upon this head I fully explained myſelf in my letter to the late Lord Anſon *, and ſhall therefore decline ſaying any thing further of it in this place.

I flatter myſelf, that what has here lately happened will tend to occaſion the applying of an apparatus of this ſort to all buildings, at leaſt, of value and extent. No ſteeple ſhould certainly be without it; and in moſt, if the iron work of the weather-cock can be eaſily got at, it may be adapted with very little trouble or expence. It is only neceſſary to make a metallic communication between this iron work and the lead, which carries off the water. This frequently reaches to the ground or very near it. From the bottom of this, the metallic communication ſhould continue to the neareſt water, or at leaſt to very moiſt ground; though where it can be procured, water ſhould be preferred. Care muſt be taken likewiſe, that metallic communications be added to ſuch parts of the lead, which ſerve to convey the water from the top, as do not already touch or come near each other. And theſe may be either of lead, or of copper wire, ſuch as I have before mentioned. In thunder ſtorms attended with rain, ſufficient in quan-

* Philoſophical Tranſactions, Vol. LII. p. 629.

tity

tity to run off in ſtreams, a great portion of the electric matter runs off in, and is diſſipated by, theſe ſtreams; and buildings are thereby preſerved from damage.

What happened to St. Bride's cannot but give us ſome apprehenſions for that moſt noble edifice in its neighbourhood; I mean St. Paul's. This is above an hundred foot higher than St. Bride's, and therefore more in the way of accident from thunder ſtorms. Upon its mangnificent lanthorn is placed a croſs of metal, which is inſerted into the ſtone of the lanthorn; and this is ſupported by a truncated cone of brickwork, which ariſes from the arches of ſtone below. The cupola is covered with lead, which is continued to the ſpouts of the ſame material. Theſe bring down the water to the ſtone gallery under the cupola, and end within about a foot of the ſtone. From hence the water is conveyed a conſiderable diſtance, in a ſtone trough or channel, to the leaden ſpouts; and theſe are carried down the building, and terminate, as I was informed upon inquiry, in the common ſewer. By this arrangement the metallic communication is interrupted. In thunder ſtorms during rain, the water carries off in its ſtreams the electricity, as perfectly, as the moſt compleat metallic communication would; but when there is no rain, it is otherwiſe; and theſe interruptions are the great cauſe of danger. To leſſen which, as far as we can conclude at preſent, it would be expedient to make, by the means of ſeveral copper wires, ſmall rods, or pieces of lead, a metallic communication between the gilded croſs, and the lead of the cupola: and again, from the leaden ſpouts of the ſtone gallery

gallery to thoſe, which bring the water thence; care being taken that, from the bottom of theſe laſt, there ſhould be a metallic communication, if there ſhould be found to be none at preſent, with the water in the common ſewer. Thus, without much expence, a compleat metallic communication may be made between the top of St. Paul's church, and the water; which had it been done at St. Bride's, the ravages ſo lately experienced had in all probability been prevented.

From conſidering the circumſtances of this thunder ſtorm, I cannot but be of opinion, that the injury done to St. Bride's prevented miſchief to St. Paul's. St. Bride's is a very high building, and within a ſmall diſtance nearly Weſt of St. Paul's. When this diſtance is conſidered, and that the lightning came in the direction of St. Bride's to St. Paul's, and that when the thunder cloud came near the former, it exploded there, and parted with much of its force; what was left did no damage to the latter, tho' the much higher and more expoſed building, and having a metallic croſs at its top.

I have recommended as metallic conductors copper wires of the ſize of a gooſe quill; as, when of that thickneſs, they may eaſily be bent to any direction; and, where thought neceſſary, any number may be employed. I look upon this as a kind of ſtandard, from what Dr. Franklin wrote to Monſ. Dalibard of Paris upon this ſubject *. He obſerves, in a church which ſuffered greatly by lightning at Newbury in New-England, that though a ſmall wire was beaten to pieces by lightning, and diſſipated by its force, the rod of a pendulum conducted the whole without

* See Phil. Tranſ. Vol. XLIX. p. 305.

being

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being melted or otherwiſe injured by it; and that, great as the quantity was in this inſtance, and which utterly deſtroyed the ſmall wire, no damage was done to the building, as far as the ſmall wire, and the pendulum of the clock extended: and in the remarkable inſtance, mentioned by Mr. Kinnerſley in his * letter to Dr. Franklin, where a braſs wire of about two lines thick, ten inches long, and terminating in a very acute point, was inſerted into the iron rod, about two inches and half only of its top were melted by the lightning; the remaining part of it tranſmitting the lightning without being fuſed by it.

You will obſerve in this diſquiſition, that I have no where mentioned the apparatus attracting the lightning. I have avoided introducing the term *attraction* here, operating as an active principle; as I conſider the apparatus purely paſſive, and only affording, from the aptneſs of its parts to that purpoſe, an eaſy and uninterrupted paſſage to the lightning, and thereby preventing its violent efforts.

You will pardon, Sir, this long digreſſion in relation to St. Bride's church; as it gives ſo poſitive and explicit an anſwer to part of your ſeventh queſtion; ſuch a one as could not, without the late thunder ſtorm, have been furniſhed, at leaſt from hence: To wit, that, without a proper apparatus, weather-cocks placed at the tops of any buildings are dangerous to them in thunder ſtorms; but more eſpecially to powder magazines.

The accidents, which have lately happened to St. Bride's and South Weald churches, if conſidered as great electrical experiments, furniſh very important, and, I flatter myſelf, uſeful concluſions. They are too hazardous

* Philoſophical Tranſactions, Vol. LIII. p. 96.

and

and expenſive however, to wiſh to ſee often repeated.

If the erecting of an apparatus of this ſort ſhould become general in countries where thunder ſtorms are frequent and often attended with miſchief, though damage ſhould really be averted by it, the operation of the apparatus would be unſeen, and therefore unknown, unleſs in ſuch rare inſtances as that mentioned by Mr. Kinnerſly. To make its effects apparent, as has been hinted to me by Dr. Heberden, a very deſervedly eminent phyſician here, if chains are employed as metallic communications, inſtead of wires or rods, whenever the lightning comes near enough to affect the apparatus in a conſiderable degree, it will without miſchief be viſible in the dark, by its ſparkling and ſnapping in its paſſage, at the links of the chain.

The effects of the apparatus may be obſerved in another manner. If the metallic communications are by the means of a wire or ſingle rod, there may be, in ſome part of its length, in any place convenient for obſervation, a ſpace left where the metal is diſcontinued; but this ſpace ſhould not exceed two inches. The two extremities of the metal at this interruption ſhould be furniſhed with braſs knobs not leſs than an inch in diameter. By this method, though the effects of the apparatus would not be conſiderably leſſened, they might be obſerved. For at times, when no lightening was viſible, but when clouds replete with it came near the apparatus, or rain from them fell upon it, there would be a ſnapping from one of the braſs knobs to the other. When indeed the lightning was near, there would not only be this ſnapping; but, if the cauſe was great, a ſtream of fire would be

ſeen, as in M. Romas's kite *, to paſs from one of theſe to the other, as the beſt and neareſt conductor. If danger however is apprehended, a piece of chain may be always at hand to be hung occaſionally upon the upper knob, ſo as readily to fall in contact with the lower. Otherwiſe, if while the metallic communication is divided, though when entire it is apprehended it may be touched with ſafety, a perſon ſhould touch the rod above the diviſion and at the ſame time touch or come very near the rod below the diviſion with any part of his body; and at the ſame inſtant if a ſmart ſtroke of lightning affected the apparatus, he would certainly be deſtroyed, as happened to profeſſor Richmann at Peterſbourg; the lightning going through his body from one part of the apparatus to the other, which it is believed it will not do, while the metallic communication is compleat.

VIII. I have not heard that there has been here of late any particular mode of buildings, adapted to powder magazines, to diminiſh the ſhock of the exploſion in caſe of accident: nor do I believe that any attention has been here given, in conſtructing theſe buildings, to prevent, by an apparatus of this kind, the effects of lightning.

Theſe, my Lord, are my anſwers to M. Calandrini's queſtions. If they are ſatisfactory to that ingenious gentleman, or have the leaſt tendency to public utility, I ſhall be gratified. As I know your Lordſhip's zeal for philoſophical diſcuſſions, I have taken the liberty of ſending you theſe queries and

* Philoſophical Tranſactions, Vol. LII. p. 341.

my

my anſwers to them, as a teſtimony of the very great eſteem and regard, with which I am,

My Lord,

Your Lordſhip's

moſt obedient,

humble ſervant,

Lincoln's Inn-Fields,
June 26th, 1764.

W. Watſon.

XLI. *An Account of the Effects of Lightning in* St. Bride's Church, Fleet-ſtreet, *on the* 18th *of* June 1764: *In a Letter to Mr.* Benjamin Wilſon, *F. R. S. from* Edward Delaval *Eſq*; *F. R. S.*

SIR,

Read June 28, 1764. THE incloſed is an account of the effects of the lightning on the ſteeple and ſpire of St. Bride's church, with drawings [TAB. XIV. XV.] which very accurately expreſs the parts damaged by it.

I thought it would be of uſe, by deſcribing the ſeveral circumſtances of this accident, to ſhew more