

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. Transf. 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. Kinnerley, 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 afford-
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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 its 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 its operation their electricity brought to the same standard with that of the earth in its neighbourhood, and *vice versa*; 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. Kinneresley of Pennsylvania. 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. Transf. Vol. XLVIII. page 215.

† The diameter of a piece of Mr. Kinneresley'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
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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 height, 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,
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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.

Since

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 completely 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 lightning, 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 lightning 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,
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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 surprising.

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
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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 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 magnificent 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. Transf. Vol. XLIX. p. 305.

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 SouthWeald 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 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. Kinnerfly. 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 lightning 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 complete.

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 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. Watfon.

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.*

S I R,

Read June 28, 1764. **T**HE 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