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TORBERN BERGMAN AS A LIGHTNING SCIENTIST

A Bicentenary Memorial of Swedish Lightning Research in the Context of 18th-century Electrical Discoveries

Torbern Bergman — 1735-1784 — well-known Swedish chemist, also devoted himself to extensive research in electricity and physical phenomena in nature. The author, Dr D. Müller-Hillebrand, Uppsala University, is research professor of electrophysics especially for the study of atmospheric electric discharges.

Two hundred years ago Torbern Bergman gave a lecture in the Royal Academy of Science, in which he discussed the possibilities of protection against lightning. At that time there were many difficulties to be overcome in applying the results of the research into electrical phenomena being carried out in all countries. Today we cannot really comprehend and fully appreciate the views of the scientists of that time, unless they are displayed in a broader context. The question of protection against lightning was no simple matter. At that time no scientist in Europe could recommend the construction of lightning conductors without testing the matter within the framework of different investigators' views. Fundamental discoveries, new theories, wrongly interpreted experiments, the views of experts and the opinions of amateurs, belief and superstition, all these made up the background against which Torbern Bergman presented his opinions and which we shall illustrate in more detail below.

Lightning Research in Uppsala in 1755.

"Why did the lightning strike a house in the square, and not the 'conductor rod' on the Observatory?" P. Guden asked this question in a publication *On Safety from Lightning,* written in 1774 (1). The phenomenon of the lightning path was discussed in connection with a question which even today troubles many laymen and which is dealt with in pseudo-scientific publications, namely, can a metal rod —a lightning conductor—attract lightning? As proof that this is not the case, Guden cites this observation in Uppsala and refers to a short article in a German periodical which gave interested readers information about natural phenomena (2). We read in this article that, as early as 1753, investigations into atmospheric electricity had begun at the Astronomical Observatory in Uppsala, occasioned by the classical experiments at Marly-la-Ville in France carried out by Jean François D'Alibard on the 10th of May, 1752, and a week later by M. de Lor in Paris. These experiments elucidated the electrical state of the atmosphere in thunder, rain and hail. This was three years after Benjamin Franklin's famous suggestion (3) for deciding by experiment "the question whether the clouds that contain lightning are electrified or not" by setting up an insulated metal rod, 7-10 m in length and sharply pointed at the top. If the atmosphere were electric, sparks

would come from the rod. Professor Richmann's tragic death in August 1753 as a result of a lightning discharge aroused great attention in professional circles. The experiments were not, however, broken off but were continued in Uppsala, though throughout 1753 and 1754 they yielded no results. But on the 29th of July, 1755, lightning struck a house in Stora Torget about 300 m from the Observatory. Only two weak sparks were seen to come from the rod. The observer, who thought that the conductor was not sufficiently "effective" on account of its rusty tip, had it gilded in order to obtain a better result. At the suggestion of Anders Celsius (1701-1744), the then Professor of Astronomy, the Astronomical Observatory had been built in Svartbäcksgatan, not far from Stora Torget. We do not know any more about these electrical investigations on the roof of the Observatory. The building rose high above the surrounding built-up area. However, according to modern experiments, the roof was not very suitable for such investigations, as the high part of the central building must have disturbed the electrical field on the roof.

Torbern Bergman as Student and Lecturer.

Bengt Ferner, who from 1751 was "observator" at the Astronomical Observatory and from 1757 to 1758 a professor at Uppsala University, had Torbern Bergman as a pupil. The latter had his first contact with atmospheric electricity in his twenties, by being present at the above-mentioned experiments.

Torbern Bergman, who was born in 1735 in Katharinebergs Kungsgård in Västergötland, went to Uppsala as a student in 1752, and took his first degree *(fil. kand.)* in 1756 after assiduous studies in mathematics, philosophy and science in all its branches. One of his teachers was Samuel Klingenstierna, Professor of Mathematics and Physics, who in 1755, the same year as Ferner carried out his experiments on the Observatory roof, summarized contemporary knowledge of electricity in a lecture in the Royal Academy of Science (5). This lecture reflects extensive and original knowledge, gained not only by reading—he had already translated the fundamental work by P. van Musschenbroek, of Leyden, which through its English translation in 1744 *(The Elements of Natural Philosophy)* had become well known—but also by his own experiments.

Bergman gained the doctorate in 1758 with a thesis entitled *De Interpolatione Astronomica.* In the same year he published a disserta-

tion entitled *De Attractione Universali* and, as a lecturer, taught, among other things, experimental physics, which he made especially interesting for his listeners by the use of a large electricity machine. His physical researches into the explanation of the rainbow (1759), into twilight (1760) and into the Aurora Borealis (1764) made him known as a very gifted scientist.

Torbern Bergman's Lecture in the Royal Academy of Science.

As the subject of his installation lecture in the Royal Academy of Science on the 23rd of May, 1764, Bergman chose "The possibility of preventing the harmful effects of lightning." The lecture was published in 1764 in Swedish (6) and in 1768 in German (7). It consists of 103 printed pages and contains a remarkable collection of observations and publications, which Torbern Bergman presented in a very personal style. The subject was very topical at that time, not least on account of the fact that the question of protection against lightning had not yet been clarified in Europe. A contributory factor was that a great authority in the sphere of physics, the Abbé Nollet, of Paris, who devoted himself particularly to electrical questions (8), did not agree with Benjamin Franklin's views on the physics of electricity or on the problems of protection. Nollet's text-book of physics achieved a large circulation (9). As early as 1758, Johann Carl Wilke, who was born in Wismar three years before Torbern Bergman, brought up in Stockholm and was a student at Uppsala up to 1751 (10), had translated Benjamin Franklin's letters on electricity from English into German *(New Experiments and Observations on Electricity made at Philadelphia in America)* (11). To this translation Wilke added 130 printed pages of commentary and 7 pages of appendices with his own investigations into thunderclouds, in reaction to Nollet's critical attitude towards Franklin's views. Wilke particularly emphasizes Franklin's suggestion of protecting buildings by lightning conductors, and concerns himself with Nollet's preconceived idea that the magnitude of the lightning stroke cannot be controlled by human means.

Torbern Bergman's work had a remarkable fate. It did not become sufficiently well known and was not reviewed in a single periodical. Thus its publication was forgotten, in spite of the fact that the title was included in 1769 in a bibliography published by Krünitz (12), which summarized publications on electricity. A contributory

factor may have been that Bergman, who was appointed Professor of Chemistry at Uppsala in 1767, was devoting the whole of his energy to chemistry and gaining a world-wide reputation as the founder of modern qualitative and quantitative chemistry, without, however, completely refraining from discussing questions connected with thunderstorms (13).

Shortly before Bergman's untimely death in 1784 at Medevi Brunn, where he had gone to recover his health, Count Marsilius Landriani had written to him, asking for his views on lightning protection. When Landriani did not get a reply, he published in 1784 a comprehensive treatise *Dell'utilita dei conduttori ellectrici* (14). In the preface he expresses regret at having to publish the essay incomplete, without having waited for answers from Bergman and others.

About 100 years later H. Meidinger published a history of lightning conductors, in which he mentions that he could not get hold of Bergman's thesis (15). In 1952 the Royal Academy of Science in Stockholm held a solemn meeting to commemorate the fact that experimental atmospheric electricity was then 200 years old, dating from D'Alibard's experiments. Torbern Bergman's achievement was mentioned only as a small contribution to the question of lightning protection. However, there must have been some confusion in this case, probably with the Klingenstierna lecture (5), so that Bergman's lecture never received the credit it ought to have received (16). Before we discuss Bergman's thesis, we shall illustrate briefly the first step forward in electrical theory after the discovery of the condenser.

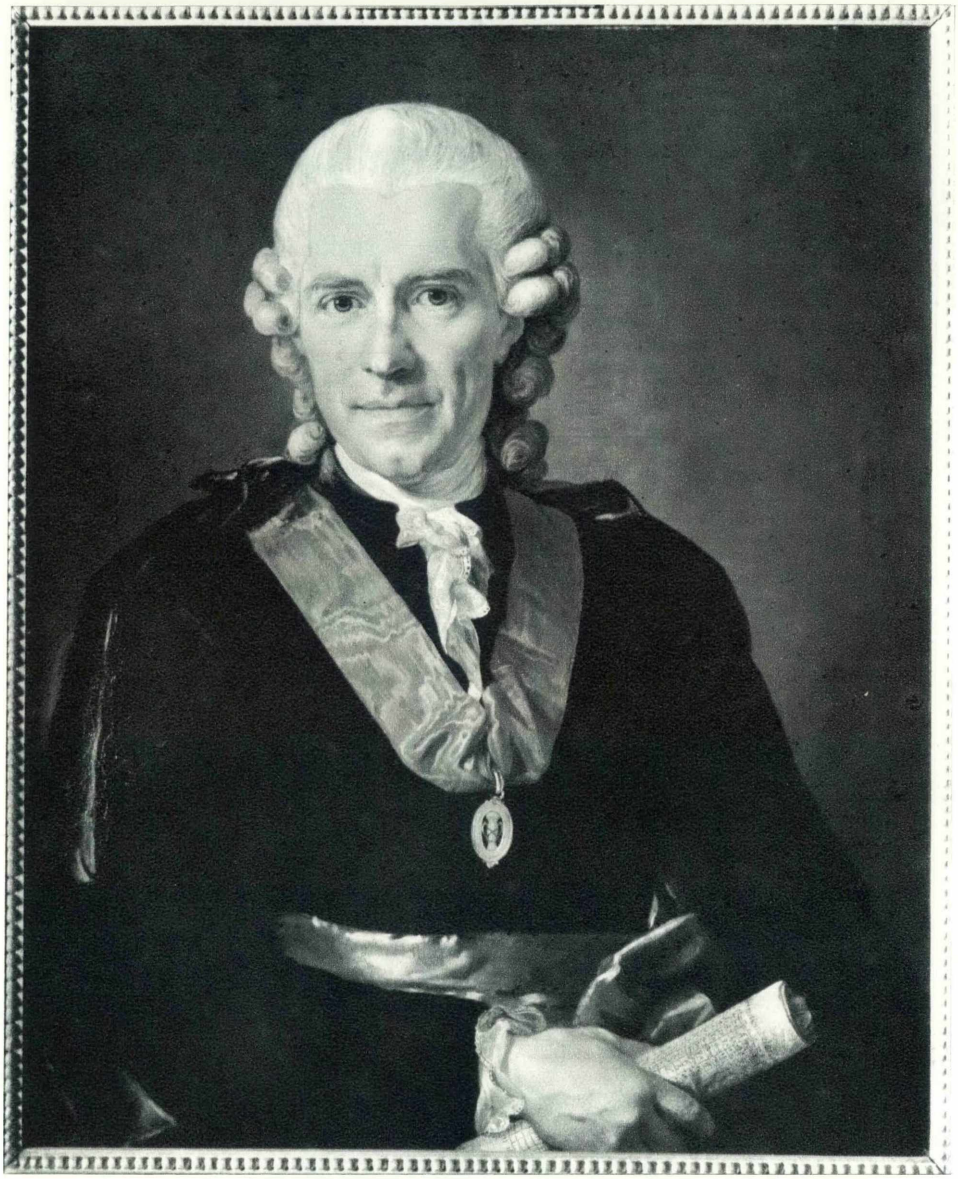
The Principles of Electricity—a Fashionable Science.

The year 1746 sees the birth of a new epoch in electrical research. The electricity machine was improved, Leyden jars on the Musschenbroek model were available, and experimental electricity investigations were being carried out in many countries. As early as 1708 William Wall in England had drawn a parallel between the "cracklings and light" produced when amber was subjected to friction and "thunder and lightning." But it was a long time before a serious study of electrical phenomena led to safer analogies. In 1746 J. H. Winkler published in Leipzig a book (20) containing a list of resemblances between the lightning phenomenon and electrical phenomena. The German pastor A. G. Rosenberg states in 1745 that "In two or three years research into electrical effects has progressed further than in

the previous 50 years, thanks to the industry of our scientists. Who knows how soon the time will come, when someone will be able to draw extraordinarily great and wholesome benefit from electricity? Perhaps it will be possible to understand more fully the nature and effects of lightning" (17).

The lightning phenomenon was beginning to be studied in many countries. Thus Daniel Tilas, who was a geologist and mineralogist, besides being President of the Royal Academy of Science in 1742, published in the same year (1745) an accurate description of lightning striking a hut and producing devastating effects like those following an explosion. Tilas draws the conclusion that "This flash of lightning can be imagined as a bomb filled with shooting stars" (18). In 1749 Nils Palmstierna, an influential politician, published his *Accounts of Some Remarkable Strokes of Lightning* (19). These included the story of how lightning had "bored through" a large stone in Solna church (1719), and on another occasion a large pile of boards struck by lightning is described: "Only 20 metres away (from Palmstierna) marks had been left on the boards like those made by a plane and a hole was made in the ground" (1740). Marks left by a lightning stroke in Östervåla church in Västmanland (lightning had struck the church twice during the same thunderstorm in 1746) were described precisely, and the destruction, which was like that following an explosion, was described in 19 detailed sections.

Finally comes a description of a fire-ball. During a thunderstorm in July 1744 a woman was just going to shut the damper on the stove, in order to prevent a draught in the cottage, when "a fire-ball as big as a clenched fist" rolled slowly down the chimney onto the floor, without doing any damage. The woman ran out into the vestibule, and the fire-ball followed and went out through the door and rolled in the direction of a barn. At that very moment lightning struck the barn with such a loud crash that the woman fainted in the vestibule. The barn was burnt out. At the same time a servant-girl had been driving home the sheep and was quite near the farm. She saw how the lightning completely smashed some willows (trees of the genus *Salix*) outside the farm and, a moment later, some fence poles. As she was hurrying home and had just got to the farm, she saw the lightning strike the barn. Palmstierna presents these descriptions "to help us to grasp the wonderful works of Nature by certain rules." He also expresses the hope that electrical experiments may be carried out in



Torbern Bergman, 1735—1784.
Painting: Lorentz Pasch d.y. 1778,
Uppsala University, Uppsala.
(Photo: Svenska Porträttarkivet, Nationalmuseum.)

INTRÅDES-TAL,

OM

Möjeligheten at förekomma Åskans skadeliga verkningar;

HÅLLIT FÖR

KONGL. VETENSKAPS ACADEMIEN

DEN 23 MAJI 1764

AF

TORBERN BERGMAN,

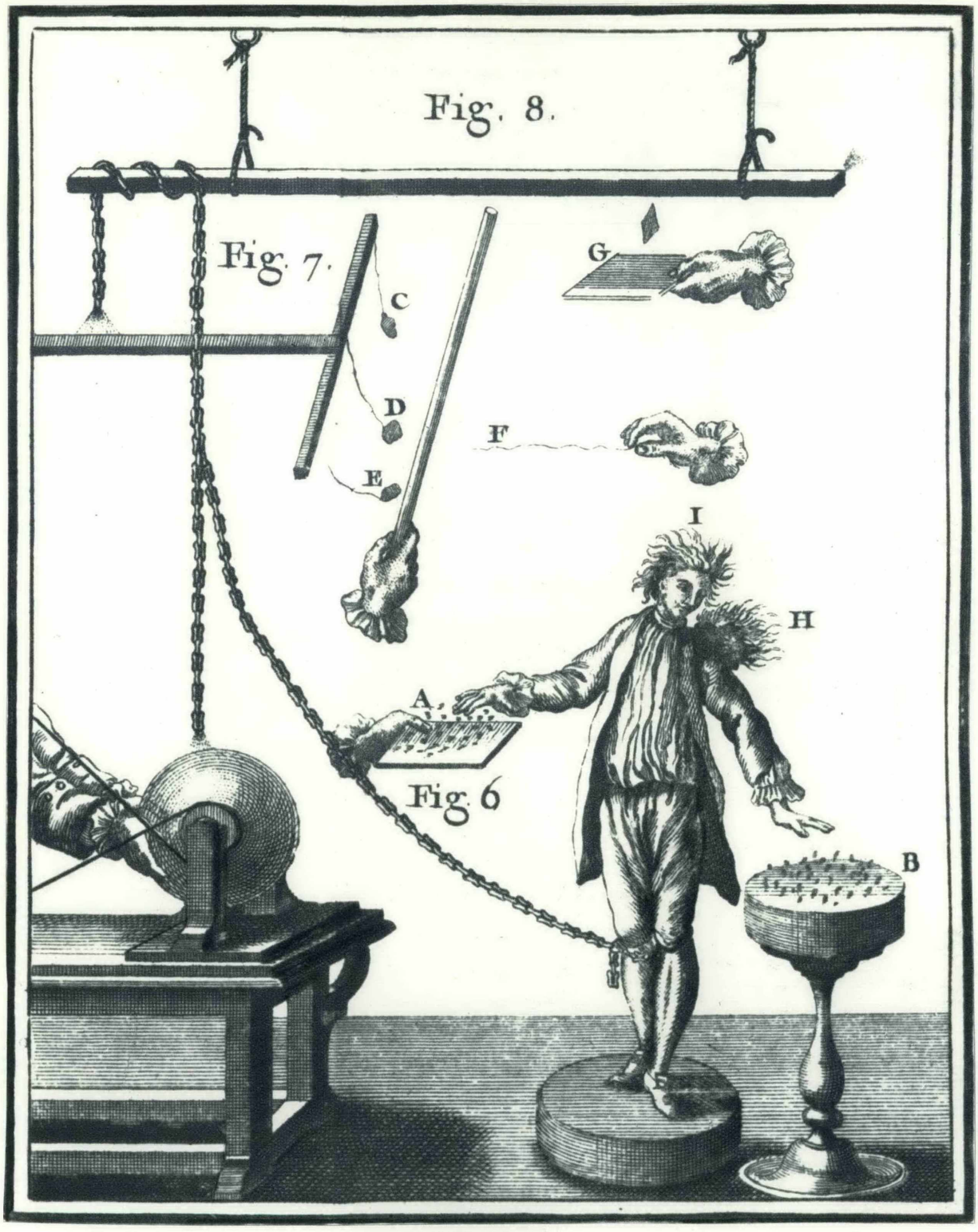
Adjunct uti Mathematiken och Naturkunnigheten vid Kongl. Academien i Upsala, samt Ledamot af Kejserliga Academia Naturæ Curiosorum.



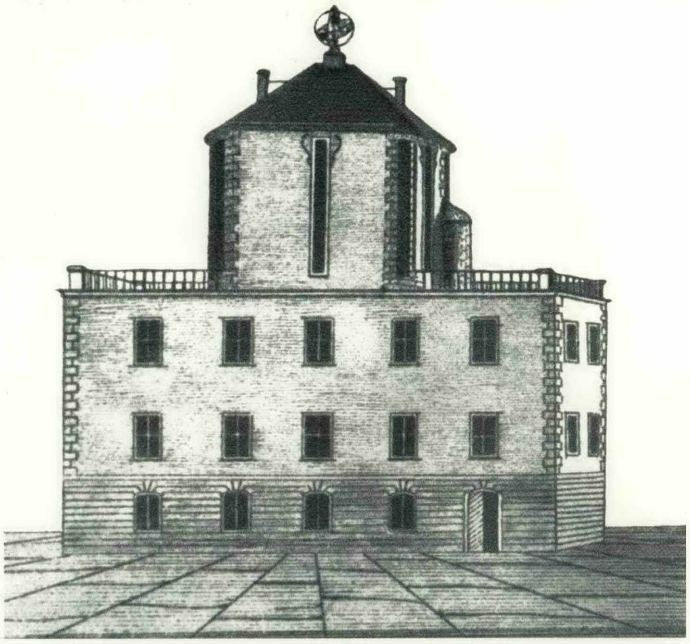
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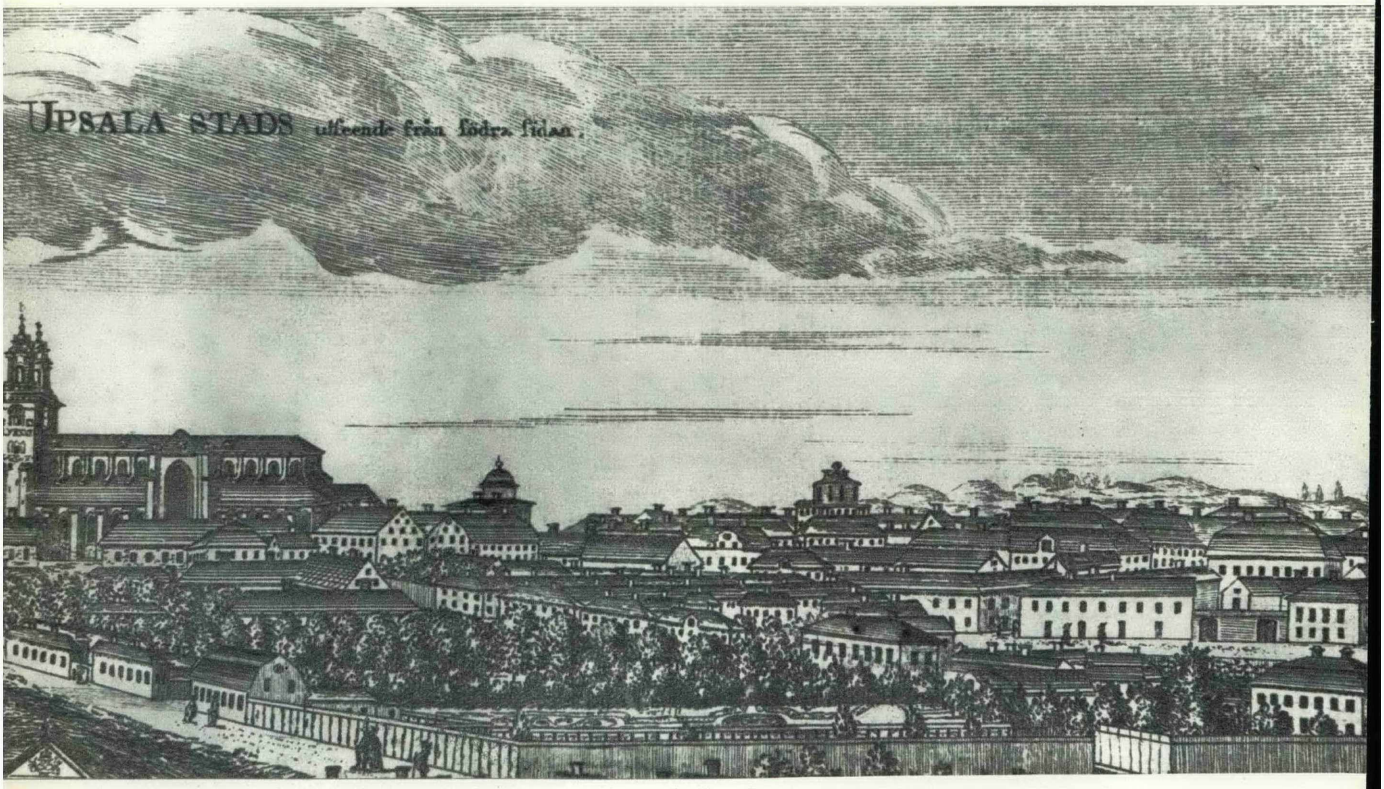
The title page of Torbern Bergman's installation lecture.



Electrical experiments (J. A. Nollet, Leçons de Physique, tome sixième, Paris 1764).



Uppsala University's Astronomical Observatory in 1741, from Busser's Outline of a Description of Uppsala.



Uppsala from the south with the Astronomical Observatory to the right of the centre. Engraving by F. Akrel (1770).

future with more powerful electrical machines than hitherto. The latter comment shows that the electrical nature of lightning had been discussed among the members of the Royal Academy of Science—Palmstierna was not a physicist—before Benjamin Franklin's Letter V on the electrical nature of lightning (3), addressed to Dr John Mitchell, of London, on the 29th of April, 1749, had had time to become known in Sweden. Probably Winkler's book was the topic of the discussion. In this book (20), published in 1746, there is an account of electrical experiments with Leyden jars. Winkler draws many comparisons between lightning and electrical sparks.

Palmstierna's aim in collecting material about lightning strokes is of no importance today, except for one or two special applications. One of these is the question of ball lightning, which has again become topical in connection with problems of plasma physics and ultra-high-frequency phenomena. Here we still have a collection of observations which can be used to support our theories and because of this Palmstierna's report on fire-balls is of special interest today. His fire-ball lasted from 10 to 20 seconds. This is in good agreement with other reports. The origin of the fire-ball between two flashes of lightning at the time intervals mentioned is especially interesting. The ball-lightning phenomenon is still in dispute and is far from being fully clarified. We are looking for a primary phenomenon in the cloud or between the cloud and the earth which can generate ball-lightning. It must in this case be a discharge lasting many seconds, which produces ultra-high-frequency waves (21). Up to now, we have not succeeded in producing spherical discharges in air at atmospheric pressure.

Electrical experiments were very popular. In many countries they were shown at the royal courts. For example, in 1745 Klingenstierna, the Professor of Mathematics at Uppsala University, carried out electrical experiments before the then Crown Prince, Adolf Fredrik, and his consort, Lovisa Ulrika (22, pp. 283, 500). These experiments were probably serious demonstrations of the electrical research of the time, judging by Klingenstierna's work and disposition. This was not always the case, however. In Paris, the Abbé Nollet presented a "grand spectacle" before Louis XV. He passed a condenser discharge through 180 soldiers, who, as they were all holding hands, jumped into the air at the same time, much to the delight and amusement of the court. On another occasion he repeated these

electric charges through 700 monks, who reacted with the precision of "the most perfect corps de ballet" (3b, p. 48). Nollet's qualifications as a scientist were criticized by Ferner thus: "He is more inclined to make the facts fit his theory than to adapt his theories to the facts, as research demands" (4, p. XLIII).

The result of the popularization of electrical research was that both qualified and unqualified persons devoted themselves to it. In 1957 Maurice Daumas stated (23): "Pour la première fois peut-être dans l'histoire le public non cultivé de la rue avait la révélation d'une puissance mystérieuse de la découverte scientifique."

The Death of Richmann.

In American literature Richmann is described as "a Swedish physicist," as in, for example, the long biography of Benjamin Franklin by Carl van Doren (24, vol. 1, p. 171) and in several other books and essays. Statements about him are to be found in earlier literature, for example, that his father was a Swedish cavalry officer or captain of horse ("ryttmästare") (25, 26). This is not correct, however. Georg Wilhelm Richmann was born on the 11th of July, 1711, at Pernau in Estonia, where his father had moved from Dorpat in Estonia in 1710 during the war between Sweden and Russia. His father, Wilhelm Richmann, was royal treasurer (quaestor or "räntmästare") at Dorpat and died of the plague in Pernau, seven months before his son's birth. His mother, Anna Margareta Meyerin, sent him to study at Reval in Estonia and at Halle and Jena in Germany. While still very young, he became tutor to Count von Osterman's two sons, one of whom (Iwan) became Vice-Chancellor and the other (Feodor) Governor of Moscow. When he was 24, Richmann obtained an assistantship at the Imperial Academy of Science in St Petersburg, as it was called at that time. He became Associate Professor of Natural Science in 1741 and in 1745 obtained the chair of natural science at St Petersburg. He was married to the daughter of Lieutenant Georg Hinze, of Dorpat, whose wife, Anna Elisabeth von Sperreuter, came from a family which, until 1783, belonged to the Estonian "Landsassen" (24). We give these details at some length, in order to show that Richmann had no connections with Sweden. The name "Richmann" occurred in the Baltic countries: there was a pastor and philosopher at Riga of that name, who wrote *De Natura Metaphysica* and *De Natura Physica* and died in 1671. A doctor, Johann Richmann, pub-

lished an essay in 1667. The Richmann family, in all probability, originated in Germany. Richmann had no connections in Sweden. Otherwise Klingenstierna would have probably mentioned it in his lecture (5).

Richmann had developed an apparatus which he called an "electrical gnomon" and which could be described as a forerunner of the electrical field-strength meter. A vertical antenna, 1.2-1.5 m in length, on the roof was connected to the apparatus in the laboratory building by a wire passing through a glass insulator (perforated bottle). From this the connection—partly a metal chain and partly a length of wire —went through the building to a table on which the apparatus was placed. The investigations were carried out as early as three months after the world-famous experiments of D'Alibard at Marly in France. On the 9th of August, 1752, it was observed that the apparatus was heavily charged with electricity and, if it was touched, a sharp stroke was felt in the hand and arm. One year later, on the 6th of August, 1753, lightning struck the antenna and Richmann, who had chosen just that moment to make a reading on his apparatus, was killed. His death was immediately made known to the scientific world, including the Royal Society in London (28).

The consequence of this tragic accident was that many scientists came to consider it highly dangerous to have an insulated wire leading into a house. To be sure, the fault—the lack of earth connection—was immediately noted at the Royal Society. But the preconceived opinion, that a lightning conductor could "attract" lightning, gained ground. This view, together with Nollet's negative attitude to Franklin's lightning conductor, contributed to the fact that lightning conductors were not actually built in Europe until 1770. Opposition to them was difficult to overcome. Twenty-nine years after Richmann's death, a very skilful lawyer, Maximilian Robespierre—the well-known French revolutionary—became defence counsel in a case concerning lightning conductors (29). The plaintiff demanded that a lightning conductor on a house which belonged to a Monsieur de Vissery should be dismantled, because of the risk to the neighbours. Robespierre won the case for his client. His speech for the defence was a work of rhetorical art. He mentions Richmann, who sacrificed his life for science. He rejects the idea that the likelihood of being struck by lightning is very slight: "Ne disons pas, comme on l'a objecté, qu'il y a un million de probabilités contr'une, à chaque orage, que

nous ne serons pas frappés du tonnerre. . . . Je n'ai point vérifié ce calcul de probabilités: ce que je sais avec certitude, c'est que les victimes du tonnerre sont malheureusement trop nombreuses" (30).

Naturally it was not known that the chances of lightning striking the laboratory during a thunderstorm were very small. The result of this accident was more caution among scientists and increased scepticism as regarded lightning conductors among the public. In different articles, published more than twenty years after Richmann's death, we read discussions which end with the question: Doesn't his death prove that lightning conductors attract lightning? Richmann himself meditated about an "attraction of lightning" and shortly before his death wrote as follows, without living to see the article published (31):

> Can such investigations be carried out without any risk? May not terrible flashes originate from electrified bodies and thus danger be occasioned by this foolish science? If these misgivings can be removed at all, it can assuredly only be done by successfully proving, on the one hand, that such investigations can be made without any risks and, on the other, that safety measures can be taken in case a dangerous situation should nevertheless arise. And if this in its turn can actually be realized, only he can do it who has first ascertained by numerous observations and experiments why and under what circumstances the dangerous flash arises. Thus it is obvious that just now the natural scientists also have an opportunity of displaying courage and daring in a hazardous undertaking. For this reason no one could restrain me from carrying out such investigations, as it is, of course, my duty to carry on research in natural science to the best of my ability, and therefore I have not neglected any opportunity to both observe and to some extent define in greater detail the phenomena of natural electricity. Even last year I had investigated the effects of natural electricity, though without suitable measuring instruments. But this year I have made all preparations to enable me to study these phenomena under certain definite conditions.

Richmann's Death in the Light of Modern Research.

How do we regard this now in the light of modern research? We now have sufficient understanding of the physics of lightning to enable us to assess the lightning process, the probability of a lightning stroke and the heat effect of lightning. The approximate dimensions of Richmann's laboratory building were 15.5×9.5 m and, including the antenna (1.5 m), at most 10.5 m high. The floor surface was therefore approximately 150 m^2. The destruction in the building was relatively small: neither the iron chain which connected the antenna to the wire in the laboratory nor the iron wire itself were destroyed. Only one connecting wire to the apparatus was broken into pieces and left some scorch marks on the clothes of Richmann's engraver,

Sokolow, who was standing nearby when the accident occurred. The current strength of the flash was low.

The probability of the current magnitude is defined by a normal logarithmic distribution (32). Fifty per cent of the lightning strokes which hit the ground are, according to this distribution, greater than 16,000 A (the median value). The most probable value is 9600 A (the mode of distribution), the mean value is 21,000 A and 10 % of the flashes have a relatively high current strength of more than 50,000 A. We assume that the current strength was relatively low, e.g. 5000 A. About 90 % of the flashes have a current strength equal to or more than 5000 A. The electrical space charge, which is transferred from the cloud to earth by a stepped-leader process and from which the flash is developed, was therefore low. This weak leader channel, which is several metres in diameter, can come down to within 10 m of the ground, before a capture discharge from the ground leads the discharge to a certain point. Thus lightning can strike an object from the side. In that case the area of attraction is not more than the area with a radius corresponding to the antenna's height. In our case, this is about 350 m^2. It was precisely this phenomenon, i.e. that lightning can "strike" an object from the side, that puzzled the experts when a house in Purfleet was struck by lightning in 1777. It struck the house about 12 m from the ground, in spite of the fact that the house had a lightning conductor at a height of 19.3 m (33). The protective angle between the tip of the lightning conductor and the corner of the house, where the lightning struck, was therefore 31°. We know now, from experience with high-tension lines, that a protective angle of 30° between the line's earth wire and the phase leader is not sufficient protection against direct lightning strokes (34).

The attraction area of the house was therefore not greater than the area of a circle, the radius of which was the antenna's height, i.e. 350 m^2. From measurements with lightning counters (35) we deduce for Leningrad (St Petersburg) an average of 40 lightning strokes per 100 km^2 in a region with about 12 lightning days per year. In this connection account has been taken of recent experience with lightning counters (36). The probability of lightning striking an area of 350 m^2 is calculated to be 1.4×10^{-4} and for a flash with a current of at least 5000 A 1.25×10^{-4}. In other words, of 8000 buildings similar to the laboratory, one is struck each year by a lightning flash with a current of at least 5000 A. The chances of Richmann's labora-

tory being struck by lightning during that thunderstorm were about 1: 100,000, assuming 12 lightning days per year.

We shall now deal with the heat phenomenon in the laboratory. The report relates that the iron wire in the apparatus began to glow and then broke. This is a result of the heat impulse. Had the power been greater, the wire would have been vaporized. We can consequently estimate the heat impulse of the flash. In order to cause an iron wire, 1.5 mm^2 in cross-section—an estimated figure—to glow and break, a current heat impulse of about 0.02 kA^2s is necessary. We have measured values at our disposal today: in the 287 kV Boulder transmission line in the U.S.A. current heat impulses in direct lightning strokes have been measured for 20 years. This was done by installing 80 towers fitted with lightning conductors which had copper wires of different cross-sections connected in series, from 0.5 mm^2, 0.8 mm^2, etc. to 3.3 mm^2. During these 20 years never more than 3 wires were destroyed, with a cross-section of 1.3 mm^2 at most. In one case, 36,000 A were measured without the smallest wire being destroyed. To do this, a current heat impulse of 0.02 kA^2s would be required (37). The flash which struck Richmann, judging from this experience, was relatively weak.

The Theories of Nollet and Franklin.

Nollet (1700-1770) was a pupil of Dufay (1698-1739). In 1734 Dufay discovered the existence of two different kinds of electricity, the electricity of glass and of resin. He advanced the first theory of electrical phenomena: each neutral body had similar amounts of both types of electricity, one of which could be removed by the friction of certain bodies. Dufay showed that charged particles not only repelled one another but could also attract one another. Nollet evolved a peculiar theory for the electrical phenomena he had investigated experimentally. It must be understood that the French school was still under the influence of Descartes (1596-1650), who had denied the existence of an "empty interstellar space." He had developed the theory that interstellar space was filled with a "liquid," which carried along the planets swimming in its stream. A force acting at a distance had no place in this theory. Nollet interpreted these electrical phenomena as the result of two liquid streams flowing in opposite directions, "effluence" and "affluence." At certain points the streams were "emitted" from an electrified body and at other points "flowed

into" it. Nollet's theory of electricity is founded on a hydrodynamic hypothesis.

Franklin was not aware of Nollet's theory when he developed his own line of reasoning in 1747 and 1748. He confirmed the fact that it was either an excess of a fluid which surrounds the body like an electrical atmosphere or a deficit of this fluid. A person standing on an insulated stool, who touches the rotating glass cylinder of the electrical machine, loses some of his own electricity. At the same time, another person, also standing on an insulated stool, can draw some of the excess electricity from the glass cylinder. The electricity does not *originate* as the result of friction. The electricity which exists in every body is *collected* by friction. A body receives either an excess—a *plus* state—or a deficit—a *minus* state. The gain and the loss are concentrated on the two coatings on the Leyden jar. The charge is in the glass of the jar and not in the coating. The *plus* state of the fluid was demonstrated by Franklin in the following experiment. The flame of a candle was "snuffed out" by a ball with a positive charge, that is, the flame retreated from the ball. On the other hand, the light from the sun was not influenced. Thus far Franklin. It was many decades before the positive ions which arise in chemical-combustion reactions were discovered.

A great step forward was made by Franklin's discovery that the rotating glass cylinder could produce both negative and positive electricity, that the sum of *plus* and *minus* electricity was nil and that the "seat" of the electricity in a glass condenser was in the glass and not in the coating. Franklin's theory had one weakness, however. It was still inexplicable how two bodies with a deficit of the electric fluid, i.e. negatively charged, could repel one another, and this continued to be a difficult problem for several decades. When, 7 years later (in 1755), Klingenstierna reported on new electrical research to the Royal Academy of Science (5), he followed Franklin's line of thought with his own experiments. He expressed himself very cautiously as regarded the theory, and did not mention any names. He reported the results of the experiments as follows: "This, I say, is all that we know of this subject. . . . But those who have gone further and fancied themselves capable of finding out the further causes of this have done no more than *invented matter and movements*, according to their inclination and need, the reality of which matter and movements they have not proved, nor can prove, other than by

saying that they *believe* them to be necessary in order to explain the phenomenon." However, he did not accept Franklin's *positive* and *negative* electricity but called them *excessive* and *defective,* which, he said, "expresses their nature more accurately."

When Wilcke published Franklin's letters in 1758 in German and with his own notes (11), he took the initiative in disproving Nollet's view in opposition to Franklin—with one exception. This concerned the repulsion of negatively charged bodies. In his essay on electrical experiments with phosphorus (10, p. 99), Wilcke says in this connection: "Nollet's ingenious ideas of a simultaneously out- and inflowing materia are more appropriate to these and other experiments."

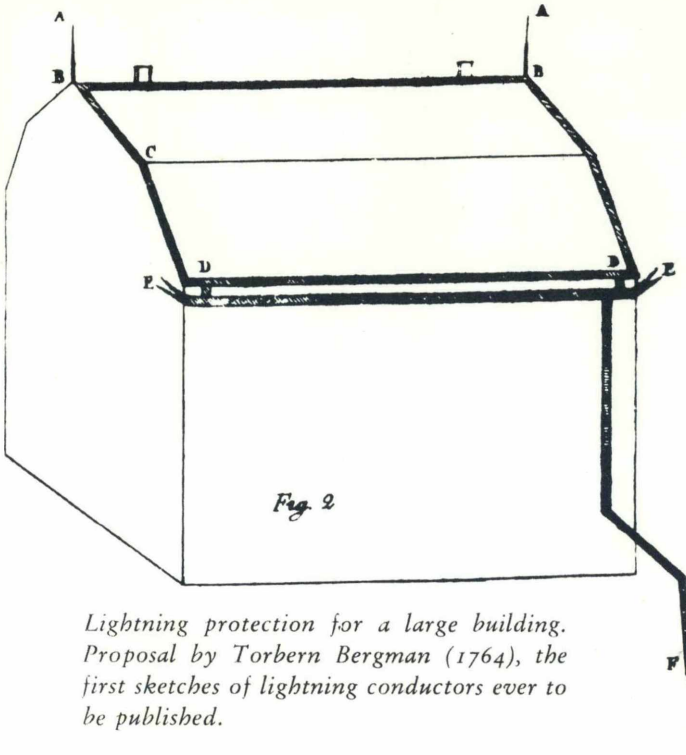
In 1763 Bergman, at the same time as but independently of Wilcke, discovered that negative electricity shows outflowing phenomena similar to positive electricity. "A severe blow to Franklin's theory. We have now to recognize two sorts of electrical substances, which each show exactly the same effects."

We have discussed Nollet's and Franklin's theories, in order to show that it took a relatively long time to clarify and explain the electrical phenomena and that there was considerable opposition to overcome, before lightning conductors could be installed in Europe.

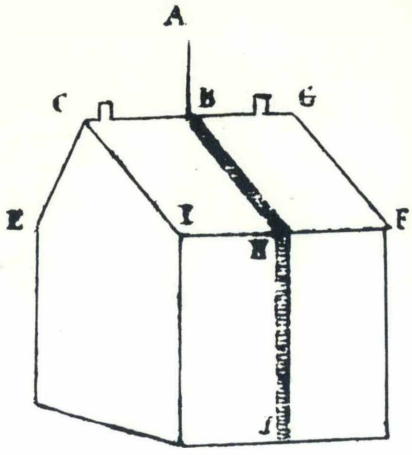
Torbern Bergman versus the Abbé Nollet.

In the year that Torbern Bergman gave his lecture (1764) there were no lightning conductors in France, Germany or Scandinavia. In England there were two or three. Nollet's view was that a lightning conductor, a simple iron rod, could not possibly carry away the powerful flow of electrical materia from very extensive clouds, which might cover whole towns. In the 7th letter in his book *Lettres sur l'électricité* (38), published in 1753, Nollet writes on this subject and asks: "Can we protect ourselves from a flood of water by installing a suction pipe at the edge of the water? If no more than pointed pieces of metal are needed to carry away the lightning, why are our towers and churches not spared?"

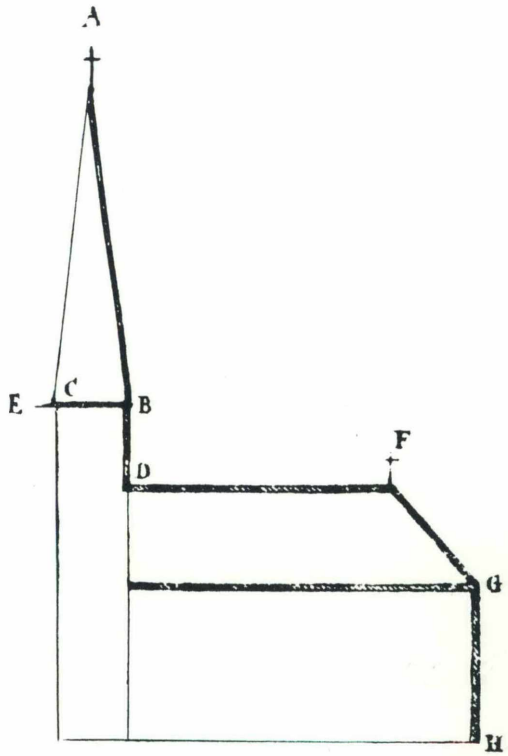
The answer to this question is the main content of Bergman's lecture. When Nollet put these rhetorical questions in 1753, only one lightning conductor had been installed in Philadelphia. This was on Franklin's house. After this there were many others in America. The first experiences with lightning conductors became known about



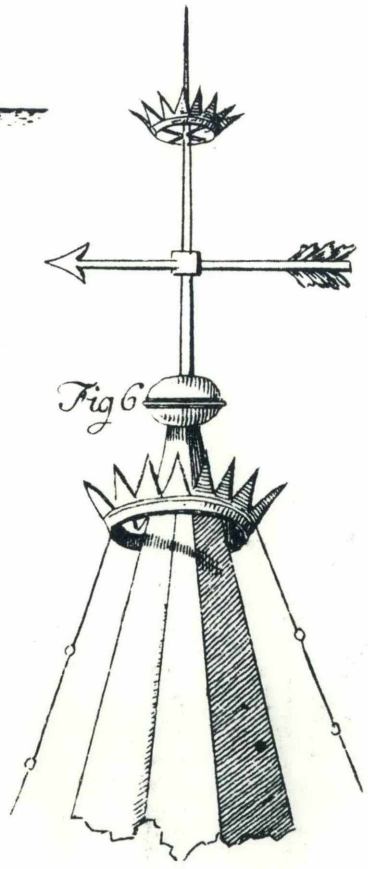
Lightning protection for a large building. Proposal by Torbern Bergman (1764), the first sketches of lightning conductors ever to be published.



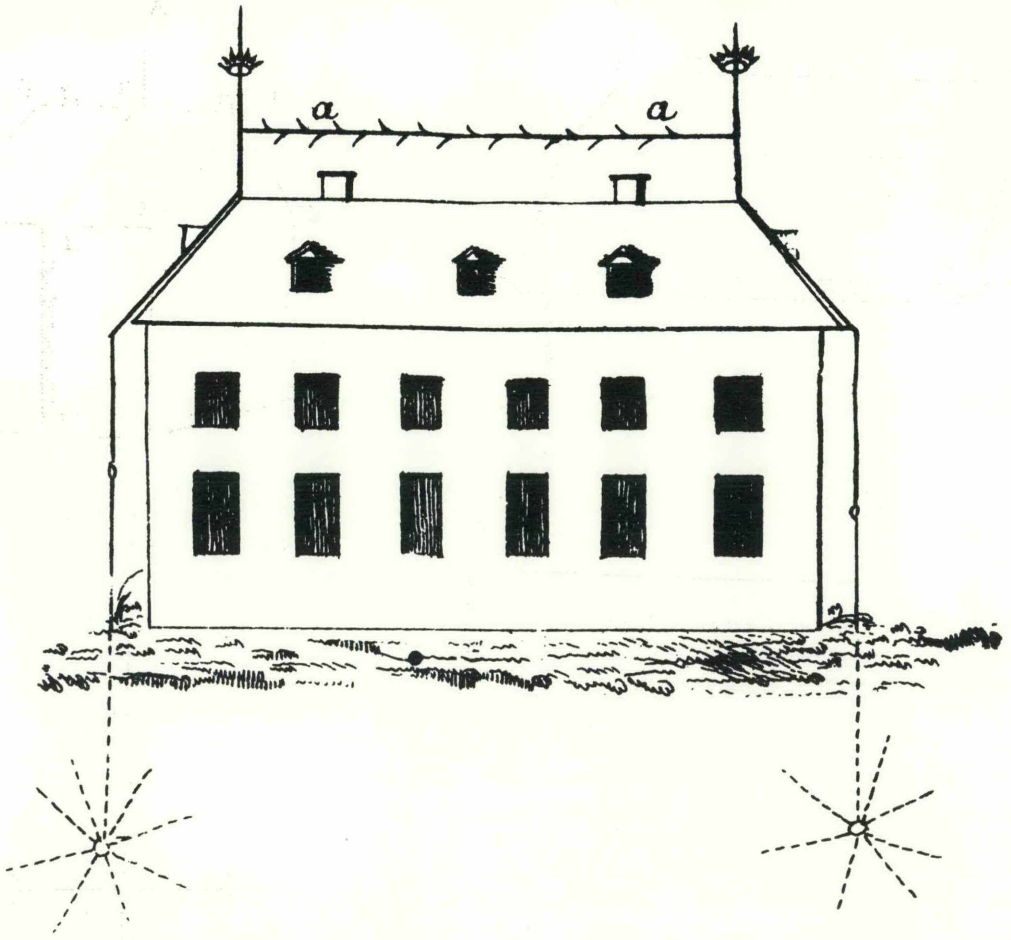
Lightning protection for a small building. Proposal by Torbern Bergman (1764).



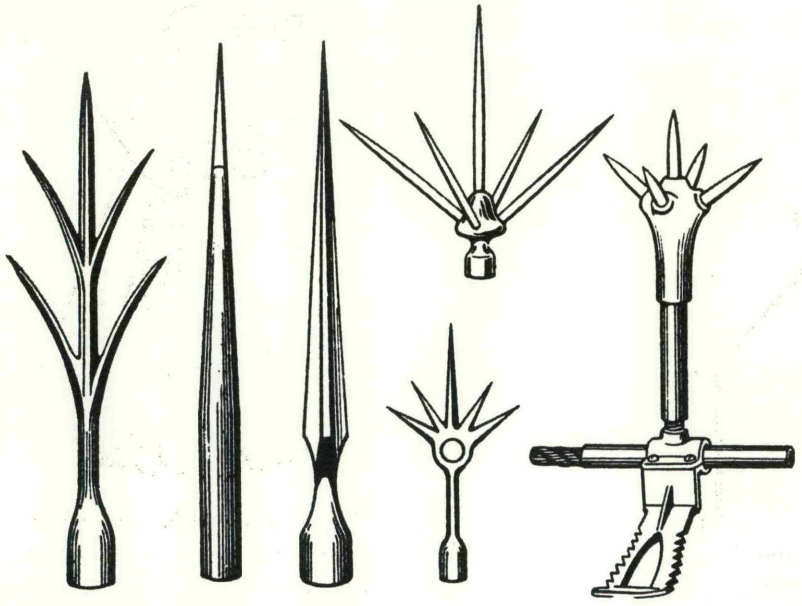
Lightning protection for a church. Proposal by Torbern Bergman (1764).



Church tower with lightning protection, according to Lichtenberg (1775).



House with lightning protection, according to Lichtenberg (1775), with the mystic property of preventing a lihtning flash by deselectrification of a cloud.



Points according to American standards (1959), not cheep and only of psychological importance.

1760. But in Europe they were still marking time. Nollet's views (39), which he presented in the same year that Bergman gave his lecture, were shared by many: "Lightning conductors may attract lightning. Let it thunder and lighten and let us ignore it, just as we ignore the rain."

In his lecture Bergman says: "A scientist strives to understand the work of Nature. But with our insufficient talents as scientists, we do not hit upon the truth all at once. We must content ourselves with tracking it down, enveloped in considerable darkness, which leads us to make new mistakes and errors. By diligent examination, we may at length, little by little, peel off the thickest layers, but we seldom get the core quite free, so that finally we have to be satisfied with a little incomplete knowledge."

Bergman said that what had decided the theme of his lecture was the recently proposed measures against the damage caused by lightning manifested in blinding flashes, dreadful thunder, smashed walls, burning churches, ships ravaged by fire, misleading compasses, shattered trees, animals struck dead and "fallen" friends. The electrical materia in the clouds can only be judged by its effects, namely, *lightning, thunder* and *strokes.* The glare of the lightning and the noise of the thunder may be intensified. Judgement only by observations may lead to wrong conclusions. The danger is seldom as great as the flashes and the thunder seem to indicate. The traces of the lightning stroke are not at all different from the artificially created effects in the laboratory. The relation between the manifestation of power and the effects created in the laboratory are not so infinitely great as we have believed up to now. The violence of the lightning flash has its origin in rapidly expanding air, and the "most terrifying force" is released in the evaporation of water. On the other hand, metals conduct the lightning so quickly that the possibility of carrying off the lightning gains "a considerable degree of likelihood." If, to use Nollet's simile, water could be led off by suction pumps at the same rate as metal points lead off electricity, then the floods of water would do no damage. But we must not stop at logical conclusions but seek proof in conclusive traces of lightning having been discharged without doing damage!

Bergman further cites some observations of St Elmo's fire without the lightning strokes, as evidence of a harmless discharge from the lightning cloud—a mistake which derives from Franklin's first inter-

pretation of his experiment in 1750 and his view of 1755, that lightning conductors have two functions, "to prevent and to conduct a stroke" (32). If lightning strikes a house, then it always follows metal as far as possible. Even a damp wall can act as a conductor. That churches and castles with pointed towers are not spared is only a question of conduction: there is no connection to ground. Richmann's fate serves to show that an earth connection was lacking.

In his lecture Bergman mentions Mariestad church, which had a new roof and tower, both iron-plated, but not connected with each other. The work on the building had not been completed. Bergman visited the church in 1762, and gave his opinion on its protection. Four days later, lightning hit the tower. The path of the lightning was as Bergman had indicated: from the tower to the roof on the inner side of the wall, which was newly plastered and damp, and from the roof down to the ground on the damp, north side of the church.

Before he demonstrates how safety against lightning can be achieved, Bergman discusses the moral angle. "If the Lord of Nature had created lightning to menace and punish the disobedient inhabitants of the earth, this would be another matter. But it does not lighten and thunder just when and where the greatest sins are being committed. . . . The Supreme Power, which, without any effort, can use the whole of Nature to punish man, did not need to create thunder in order to keep the inhabitants of the earth in check." This reflects the discussions about mankind's right to protect itself. In the addendum to his lecture Bergman mentions an American studying medicine in Uppsala, Adam Kuhn, who told him how ministers in America preached for and against lightning conductors. Those who defended the moral sanction for protection quoted, amongst other things, the Book of Proverbs, chapter XXII: "A prudent man foreseeth the evil, and hideth himself; but the simple pass on, and are punished." The importance of the religious and philosophic aspect of protection against lightning is shown by, *inter alia*, an essay published in Stuttgart by a priest, 10 years after Bergman's lecture. In this essay the priest mentions Bergman's writings and uses the whole Bible to offer relief from anxiety during a thunderstorm (40).

Before Bergman gives his instructions on protection against lightning—these are discussed later in a separate section—he states that not anyone may concern himself with this matter but only an "ex-

perienced Electricus." Otherwise the danger may be greater than with no lightning conductor. It is not simply a matter of setting up a pointed iron rod and connecting a steel wire to the ground: the dimensions must be correct. The main rule is that both the lightning "diverter" and the "adverter" must be "ready, whatever side the lightning chooses to come from," a rule which was deduced from certain observations interpreted to mean that the earth could be electric and that lightning could strike from the earth to an unelectrified cloud. The explanation for this assumption is that the electrical properties of the tourmaline had been discovered and this at the time aroused great interest and made Bergman think that the ground could be electric on the occasion of a lightning stroke. This view is the result of the contemporary theory about the origin of lightning electricity, which was discussed by Wilcke in a comprehensive account (41). The tourmaline had stimulated Bergman to make special investigations, which were completed and published two years later (42).

Towards the end of his lecture Bergman says: "Sciences without application and benefit to the public at large may well, to some extent, come into their own and satisfy man's thirst for knowledge. But as long as only these sciences are carried on, men will seldom gain the respect of society which they would otherwise deserve. The greater part of a state is concerned with other things than the increase of knowledge, and therefore regards everything as useless that does not immediately benefit their occupation."

Torbern Bergman's Protective Measures for Buildings.

Bergman gives the following instructions: "At each end of the roof ridge a flattened or round iron rod is to be erected, a few alns in length (1 aln = 2 feet = 60 cm) and with a gilded tip and/or, if desired, a metal sphere covered with spikes, so that they can absorb or emit electricity in all directions. Several pumps empty or fill more easily than one. In order to prevent rust, which has been found to prevent the conduction of the electrical materia, have the tips gilded. . . . The thickness of the lightning rod must be a decimal inch (= 30 mm), gradually tapered and pointed. The tip of the rod need rise only one or two feet above the highest part of the building. All metals are suitable, but iron is preferable, in respect of both price and durability."

He then gives the following directions: "In the case of a metal roof, all that is necessary is a metal connection with the earth. This also applies to houses with a tiled roof, in which the ridge, corners and footings are covered with metal. If there is no metal connection, one must be installed. At least on the two diagonally opposite corners, the building is to be covered with tinplate, which is to be connected to the roof plates. Tinplate gutters are to be connected to the roof plates. In this case, no special down conductors are required. All the metal parts which are found on the exterior of the building must be connected together." In the case of big and high buildings, one or more sharp points are to be installed in the corners of the eaves, for the sake of safety. In churches and other "fair-sized buildings," there should be no lack of ornamentation consisting of tips or points.

"As earth wires, one or more iron pipes may be used; they are to be connected to the rainpipes or the corners of the house. These pipes are to be connected to the nearest source of water, a well, a dam or a lake." In order to emphasize the importance of these precautions, Bergman adds that in these pipes "the lightning can be discharged if the clouds are positive, and from these pipes sufficient 'sedative' materia may be obtained when the clouds are negative."

In the addendum to his lecture Bergman gives more detailed instructions. He exemplifies the protective measures by several drawings, which are, as far as I can gather, the first sketches of lightning conductors ever to be published. As a roof conductor and as a down conductor Bergman recommends tinplate. At a church "there must be a strip of plating at least a quarter of an ell wide (= 14.8 cm) down the tower (A, B) with several points (E) on the side away from the nave (B, C)." The same points are shown in at E.

"On wooden roofs the procedure is the same, namely, covering the ridge and the corners with tin plating. On turf roofs, one or two convex, cylindrical halves must be placed, connected with the lightning rod and taken down to the earth conductor outside the house by the shortest route."

In the addendum Bergman gives some instructions for the earth conductor. If the house has two down conductors, it is sufficient if only one of them goes down into the damp earth and not into water. In small houses, which are less exposed to lightning, it may be sufficient if the earth wires go down only a few feet into the ground.

Bergman advises against conducting the "lightning materia" down

into the cellar, as it could affect the wine or fermenting liquors. Presumably Bergman is here reproducing some observations made in England (43). With this we leave Bergman's instructions, which are interesting in several respects.

As early as 1750 Franklin expressed the opinion that houses, churches and ships ought to be protected from lightning by rods with gilded tips, which should be mounted on the highest points of these exposed targets (3b, Letter V, *Opinions and Conjectures,* paragraph 20). In his Letter XII in 1753 he develops the hypothesis that "Pointed rods erected on edifices may likewise often prevent a stroke" and in 1755 he extends his views on lightning conductors in a letter to D'Alibard in Paris: "Yet, whenever my opinion is examined in Europe, nothing is considered but the probability of these rods preventing a stroke of explosion, which is only a part of the use I proposed for them; and the other part, their conducting a stroke, which they may happen not to prevent, seems to be totally forgotten, though of equal importance and advantage."

The possibility that a tip might possess a "mystic" property of preventing a lightning stroke troubled the experts for many decades. Independently of Franklin, P. Divisch had in 1754 built a "machina meteorologica," 40 m in height and with 216 needles for "de-electrifying" the cloud (32). It was not Franklin who recommended the use of multiple tips or needles. These were in use in America before 1760. In Letter XXII an account is given of lightning hitting a house in South Carolina which belonged to a Mr William Maine. The tip of the lightning conductor was a three-pronged trident, each prong about 17 cm long and equidistant from its neighbour.

Tips in every conceivable arrangement would protect against lightning. Lichtenberg's suggestion, in 1775, of furnishing church towers with tip arrangements and houses with lightning rods consisting of different tips was the logical outcome of this superstition (44). W. Snow Harris wrote in 1843 in a book which was widely read on the ability of the tips to influence a stroke of lightning: "The evidence of this action of pointed conductors in mitigating the fury of electrical discharges is as complete as any evidence from experience can be imagined" (45, p. 190). In Sweden gilded tips were used up to the 1870s. The American regulations, *Code for Protection against Lightning,* show, as late as 1959, the tips. These have only a psychological importance.

It was a great mistake to transfer the results of laboratory experiments with tips, which could neutralize electrically charged bodies, to the lightning-cloud phenomenon. In the first place, the corona current from the tip, which is seldom more than 10 μA, is much too small to be able to neutralize a cloud charge within a few minutes, and moreover the space charges can only be neutralized by "mixing" with an electrical carrier of the opposite polarity. The pre-requisite hydrodynamic conditions for this are absent. Outside atmospheric electricity, there is scarcely another branch of physics which has permitted, and continues to permit, discussions of states which are either too weak by several orders of magnitude to produce the alleged phenomena or have been measured with errors of a whole order of magnitude.

Bergman's instructions differ in many respects from Franklin's advice. Franklin states: "The lightning rod must rise from 6 to 8 feet above the highest part of the building." Bergman was of the opinion that "one or two" feet were sufficient, an idea which corresponds to modern views. In this respect Bergman was far ahead of his time: *in the middle of the 19th century* lightning rods 2 to 4 m long were recommended and in France 6 m or more. In Sweden it was the practice, according to E. Edlung, to have lightning rods rising several metres above the highest point of the building (46). Many ugly lightning conductors on our buildings today bear witness to this practice.

In America down conductors were used consisting of rods hooked into one another, without satisfactory results. Franklin asserts that "A rod in one continuous piece is preferable to one composed of links or parts hooked together" (Letter XXII). Bergman avoids the difficulty by recommending the tinplate used in building at that time and confirms that "buildings with a tiled roof or with the ridge covered with metal need no lightning rods and no special roof conductor." It is striking that this practical procedure of combining building technique with physical knowledge should have been forgotten. I. A. H. Reimarus, of Hamburg, is stated to be the inventor of this method of protecting houses, which was used for many decades. He published a comprehensive book on lightning in 1778 (47). Bergman recommended the method of using tinplate for roof conductors and down conductors in the words: "Plates and pipes should preferably be used . . . because we have learned by experience that the same quantity of

a material can absorb more electricity if the area is greater." Reimarus recommended strips of plating, partly with regard to the relatively easy erection of the connected conductors and partly on the ground that the greater area of the metal afforded better conduction.

Bergman's method of protecting houses and churches shows his independence in working out in theory and in practice the problems at hand. In his proposal he did not adhere to Wilcke's views either. Wilcke put forward his views in 1758 in his notes on Franklin's letters (3c, p. 318). He was of the opinion that attempts should be made to turn "the whole building into a single conductor. . . . The lightning flash should not come into the house without striking the conductor. . . . A high rod with a single wire is not sufficient." This proposal of Wilcke's—nowadays called Faraday's cage—was not feasible. Bergman went his own way and did not follow him. About 120 years later, no less a person than James Clerk Maxwell discussed the problem of protecting a building, independently of the earth conditions, in which gunpowder production was carried on. "It is quite sufficient to enclose the building with a network of good conducting substance" (48). Naturally, Wilcke and Bergman did not have the same conception as Maxwell when he presented this proposal, which today is regarded as quite correct. But the knowledge that they all had in common was that the earth is not a metallic conductor.

We have already quoted earlier the formerly widespread view that the earth could become electrically charged, and we shall complete this with Bergman's reference to a description by Maffei, which is to be found in his essay on lightning published in 1749 and which is one of the earliest discriptions of ball lightning in existence (49). In 1713 Maffei was with a group of travellers in an "earth room" (presumably a cellar) in the castle of Fosdinovo. "There they saw a partly white and partly blue flame rising up from the floor; the interior of the flame seemed to be in violent movement. After some moments' immobility . . . the flame spread out, giving off a sighing sound, limewash fell down from the roof and at the same moment a dreadful crack was heard."

It was many decades before it was realized what was essential and what was inessential in research into atmospheric electricity.

Bergman's Addendum to His Lecture:

Dean Rhyzelius' Brontologia.

We have already on several occasions quoted the opinions which Bergman laid down in the above-mentioned extensive addendum. Here he reproduces in 36 sections all the material which he had collected over many years. Considerations of space do not allow us to reproduce these notes in detail; we shall only quote some examples which especially concern Sweden.

Bergman cites on many occasions a strange and unique book, the *Brontologia* of Dean Rhyzelius (50), wich was published in 1721 and which contains in its four parts:

(1) A description of thunder and lightning according to God's Word and other writings (29 pages);

(2) The Christian thoughts of God-fearing people (25 pages);

(3) An account of the most remarkable strokes of lightning and other instances of great damage by fire from the year 1000 A.D. . . . in the Svea and Göta kingdoms (65 pages);

(4) A few prayers (6 pages);

An index with 157 names of devastated localities.

The book is dedicated to King Fredrik I and Queen Ulrika Eleonora. The collection begins with some big fires (1008, Björkö destroyed by the Norwegian Olov Haraldson; 1187, Sigtuna destroyed by the Estonians; 1252, the cathedral in Old Uppsala). The devastations caused by lightning begin with Strängnäs Cathedral in 1291, the Swedish navy's difficulties with "storm, hail, thunder and lightning" in 1300 during the war with the Russians, and the fire in Stockholm in 1407, caused by a flash of lightning, in which over 400 people died. From the middle of the 15th century onwards the information becomes more abundant: in 1464 Åbo Cathedral and in the same year Uppsala Cathedral, with its copper-covered tower and roof. From 1660 onwards Rhyzelius has probably obtained all the reports of great damage caused by lightning to churches. Bergman quotes particularly the following statement by Rhyzelius:

(1) As regards the question of protecting ships against lightning, there is the above-mentioned devastation of the Swedish fleet in 1300. There is also the split mast on the ship in the Swedish fleet, which in 1594 carried King Sigismund back to Poland after his coronation

The title page of Dean Rhyzelius' Brontologia (1721), a unigne book about lihtning fires during more than 600 years.

I HERRANS JESU NAMN!

BRONTOLOGIA THEOLOGICO-HISTORICA,

Thet är

Enfaldig Wåra

Och sanferdig

Berettelse,

Om

Åske-Dunder / Blixt och Skott;

Bestående af Fyra Delar.

I. En af Guds Ord och andra Skrifter tagen beskrifning om Åskans Dunder och Blixt / Eld och Kraft.

II. Gudfruchtiga menniskiors Christeliga tankar om then i himmelens sky dundrande och ilungande Gudi.

III. Sviogothia fulminibus & flammis punita, eller trowerdiga berettelser om the märkwerdigaste Åske-slag / Thorweldar och andra styrq brandstadar / som i förra och sednare tider / ifrå åhr 1000. in til thetta innewarande / på Städer / Slott / Kyrkior och andra stora Hus sig tildragit hafwa / inom Swea och Götha Rike.

IV. Några få Böner at bruka när thet Dundrar / tillika med en Tacksägelse efter öfverståndEn Blixt och Dunder.

Uti enfaldighet sammanskrifwen / och på mongas begäran / til at afträckas / framgifwen

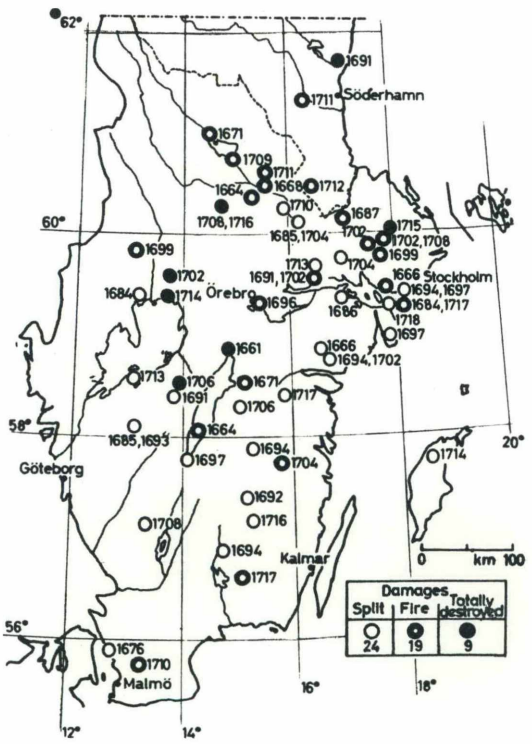
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ANDREA OLAV. RHYZELIO. W.G.

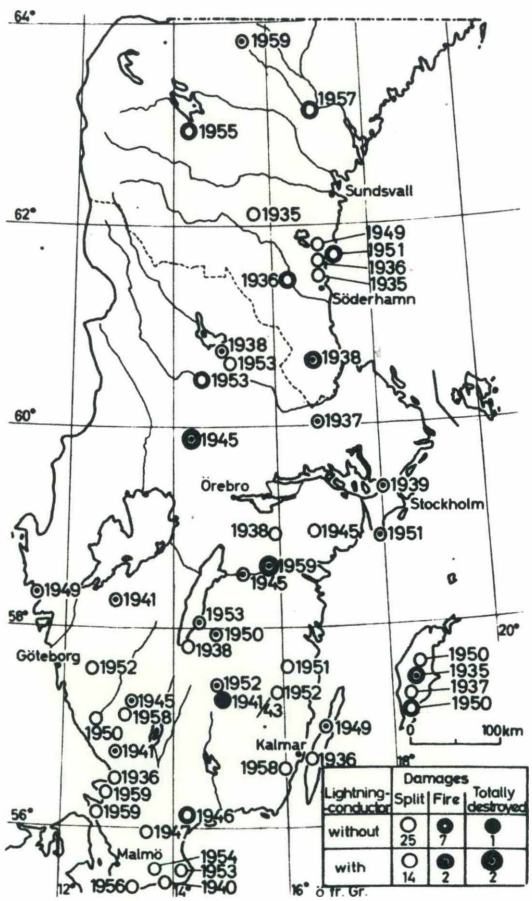
Uplagd med JOHAN LAUR. HORRNS egen bekostnad.

STOCKHOLM / Tryckt hos Kongl. Antiq. Archiv. Boktr. 1721.

Sixty years of damage done by lightning to churches in Sweden between 1661 and 1720, according to A. O. Rhyzelius (1721).



Twenty-five years of damage done by lightning to churches in Sweden between 1933 and 1959.

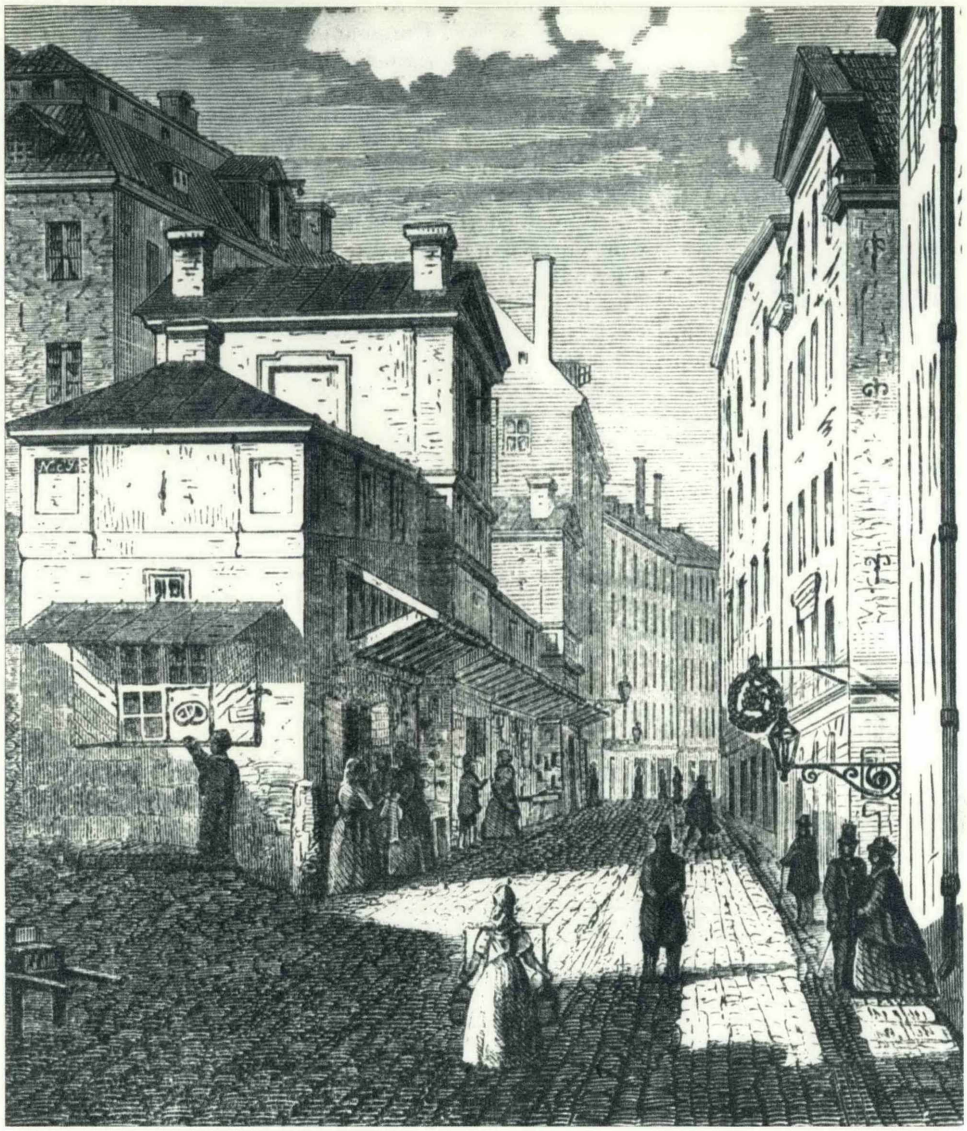




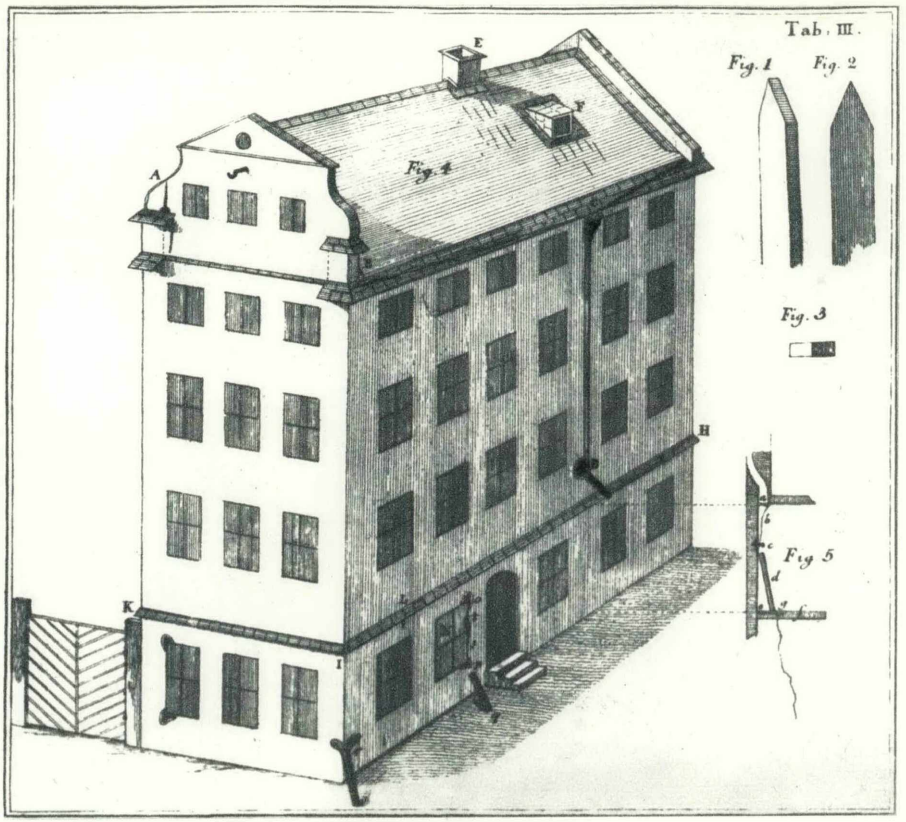
"Chapeau-paratonnerre" and "parapluie-paratonnerre", according to a proposal by J. B. Dubourg (Paris 1778).



This proposal, 14 years after Torbern Bergman's, was less suitable. Bergman warned against touching an umbrella.



Part of Österlånggatan in Stockholm after a drawing by O. A. Manker (1865). The "Stjernan" house is visible on the right. Stockholm Stadsmuseum.



The "Stjernan" house struck by lightning, after a drawing by J. C. Wilcke (1770).

Installation of a lightning conductor on Mariestad church, probably the first church in Sweden with lihtning protection. Sketch by J. C. Wilcke (1786).

in Uppsala. There is another example in the summer of 1715, when some Russian marines, headed by the Tsar, were going aboard a newly built ship, the "Narva," near St Petersburg; lightning struck the ship, which was on its way to attack Sweden with 60 cannon, 469 men and 19 officers. The ship flew into the air. The Tsar was so badly shaken that the attack was called off.

(2) Frequent strokes of lightning on high towers are illustrated by some examples: Strängnäs Cathedral, Grangärde church in Dalarna, Åbo church and Klara church in Stockholm were all struck four times. But Bergman adds: "We see many high towers which have never been struck by lightning."

(3) The explosive effects of the lightning flash are exemplified by smashed walls, for example, in 1630 at Strängnäs Cathedral, in 1670 at Sunds church in Åland, in 1699 at Danmark church near Uppsala and in 1702 at Västerås Cathedral.

Before we leave Rhyzelius' *Brontologia,* we show a collection of cases of lightning damage to churches during the 60 years from 1660 to 1720 and, as a comparison, the cases of damage to churches in country villages in modern times. If we disregard less extensive damage, which was relatively difficult for the chronicler to get hold of, we get the following numbers of cases of damage, converted to 10-year figures during the following periods:

	Partly burned	Destroyed	Total	Lightning conductors
1661-1720	3.2	1.3	4.5	Without
1933-1959	3.2	0.4	3.6	Without
	0.4	0.8	1.2	With

The number of churches in the countryside has not changed essentially over the past 300 years. The number of cases of damage to churches with lightning conductors has not decreased as much through lightning protection as one would have expected. This is a result of the installation of electricity and the modernization of the churches, which increase the risk of damage in lightning accidents (51).

Repeated Flashes.

Bergman gives many examples of the effect of lightning on living things. Thus he mentions, for example, that Luther's friend, Alexius, died by a lightning stroke (Luther, who was accompanying him on

this occasion, was blown down by it. In his mortal fear he made his promise to become a monk. This was on July 2, 1505.)

The flash may strike the same object repeatedly, a rare phenomenon that even today has not been sufficiently investigated. Bergman reports an item of news in a newspaper concerning a lightning stroke on August 2, 1763, on a cattle shed near Västerås. We may supplement this news item with the following statements from *Inrikes Tidningar* of August 15, 1762. A fire broke out owing to a lightning stroke during a violent thunderstorm. The farmer put the fire out. However, the lightning struck the cattle shed again and killed two bullocks, while the farmer was in the hayloft. Owing to the powerful stroke, the fire flared up again. The farmer shouted to his 16-year-old son to help him. The son ran to fetch more people but was killed outright by a third stroke, not far from the burning cattle shed.

Such reports must be taken with a certain amount of reserve. Newspaper accounts of rare natural phenomena often turn out to be unreliable and incorrect. The modern view of the repetition of lightning strokes on the same object can be assessed as follows. If the probability is calculated on the basis of annual mean numbers of lightning strokes, for example, 40 strokes per 100 km^2, the calculated probability will be so small that the likelihood of the story told by Bergman will be nil. If, however, we start from some observations of heat thunderstorms with thunderclouds which spread very little in a horizontal direction, we can proceed on the basis of a lightning density of about 20 flashes per km^2. The attractive area of a building is greater, the more powerful the cloud charges descending with the pre-discharges of the stroke or, in other words, the greater the current strength arising in the stroke. A cattle shed, 8 m high, may in these extreme conditions have an attractive area of 0.5 hectare. The probability of a lightning stroke will then be about 9 % and of a repetition about 5 ‰. Now the question arises, to what extent the combustion gases, which contain large quantities of positive ions, may influence the lightning path; to this question there is no definitive answer. In a calm a perceptible influence is conceivable. If the effective height of the burning building is increased owing to these combustion gases, the probability of a repetition of the lightning stroke will be increased. Thus at a height of 30 m the probability of a repetition is about 15 %. These probability figures may explain why such repetitions of a lightning stroke under certain relatively rare conditions seldom occur.

Personal Protection against Lightning.

The fact that the boy was killed instantaneously by the lightning stroke induced Bergman to make the following assertion. "To be killed by lightning is moreover said to be the easiest of all ways of dying. For one does not feel the least pain; in an instant all is over." He is of the same opinion as Franklin, who in Letter XVII of the 18th of March, 1755, writes: "Too great a charge might, indeed, kill a man. It would certainly be the easiest of all deaths." This view later led to the invention of the electric chair as the method of inflicting the death penalty in America.

In his lecture Bergman mentioned the following in connection with the question of how one should protect oneself in the open air: "Holding a sword or a little iron spike over one's head is a suggestion which is of no benefit but could well be harmful. For if the lightning goes up or down through the sword, the person's body becomes a conductor in the path of the electricity and that probably for the last time." He attacks a view which he maintains was expressed by Franklin, namely, that wet clothes should be a protection against lightning. As an experiment Franklin had tried to kill a wet rat by condenser discharges. However, the rat did not die. Bergman states: "I am quite sure that Franklin has somehow or other gone astray." It is well known that fish die in a vessel containing water, when an electric discharge is passed through the water.

In connection with the question of protection against thunder rain, Bergman makes the following suggestion: an umbrella on an iron shaft and with a point on the ferrule fastened in the ground. "One should stand under it without touching the umbrella." Should the lightning strike the shaft, you will certainly be safe, but you will receive such a shock from the powerful explosion that you will tumble over.

A proposal concerning the same safety measure was put forward 14 years later by J. B. Dubourg, one of Franklin's French friends, who in 1773 at the age of 64 had translated Franklin's *Letters* for a third French edition (3d). Nollet had died three years before. The resistance to lightning conductors had turned into a great interest in protection against lightning. But Dubourg obviously lacked the intuition as regards lightning phenomena which characterized Bergman's investigations. Dubourg's proposal (52) to fit ladies' hats and gentlemen's umbrellas with lightning conductors was less suitable than

Bergman's. The latter, of course, gives an explicit warning against touching the conducting shaft of the umbrella. If Dubourg's device were ever used, those who carried this "safety" device would in all probability be injured by the flash.

An Example of Bergman's Suggestions for Protective Measures.

Five years had passed since Bergman's lecture and still no lightning conductors had been installed. Then, on the 30th of May, 1769, lightning struck a house in Stockholm, only 150 m from where Wilcke was living in the neighbourhood of the German Church, the tower of which rose high above all the surrounding houses. The "Stjernan" house in Österlånggatan had been struck, in spite of the fact that it was no higher than the neighbouring houses. Wilcke immediately carried out a thorough investigation of all traces of the lightning and published an account with a sketch in the *Proceedings of the Royal Academy of Science* (52). Bergman made one addition, in which he gave his opinion as to the damage caused by the lightning, with the guidance of his earlier lecture. He gave his interpretation of the damage and explained his attitude to some questions which had still not been clarified.

The "Stjernan" house had several details in its construction which Bergman had especially discussed in his lecture: plating over the roof ridge and the gable, gutters and rainpipes, a skylight shutter with plating and a horizontal plated cornice, which protected the lower floor against rain. All these metal parts were not connected with each other—a protective measure which could have been easily effected. Wilcke carefully examined all the traces of the lightning, which fortunately had not done much damage, interrogated all witnesses and came to the following conclusions, which he discussed:

(1) The lightning strokes follow and seek out metal parts;

(2) Traces of lightning were found between unconnected metal parts;

(3) Tinplating, according to Bergman's suggestion, is of great value;

(4) The value of high, pointed, iron lightning rods is debatable;

(5) Lightning does not strike the highest objects.

The last conclusion especially gave rise to some speculation. Experience in Stockholm showed that high church towers were not specially exposed to lightning, for example, in the high-lying area

in the south around St Katarina's church low houses had been struck but not the church. On Kungsholmen the lightning had struck Lake Mälaren and not houses on high ground, and in the harbour ships at anchor had been damaged.

Torbern Bergman expresses his opinion, on the strength of this investigation, on phenomena which until then had been unexplained: the value of the lightning rod, the discharge to earth and the lightning path to earth. Does a point attract lightning to itself or not? All measurements argue that a point decreases the force of a stroke. But it is not necessary for a lightning rod on a house to be high. On the other hand, high iron rods with sufficient conductivity can protect the whole neighbourhood. According to Bergman, the fact that high church towers do not do this is due to the lack of a metallic path to earth in the spire. But a house is made safe if only all roof plates are connected to each other and the down conductors run through them. The earth wire does not always need to be taken down further than the damp ground, if the house is built on fairly conductive ground. And finally, the lightning path to earth creates a great many problems. "It is not easy and even often impossible to give an explanation of why the stroke struck one point rather than others in the neighbourhood" states Bergman and proposes several hypotheses, for example, that rarefied, heated air, draughts and air currents might affect the path of the lightning. It was more than 170 years before these questions were cleared up, and it will certainly be a few decades more before the interested general public accepts the physical facts.

The lightning phenomenon interests the public to a high degree. Whether qualified or not, people busy themselves with lightning problems. One of these problems is how to influence the path of the lightning, and attempts are now being made to solve it with radio-active substances (53). This is an example of completely wrong methods, as the effect is much too weak, by several orders of magnitude. The proposal would have been forgotten if business interests had not been behind these radio-active lightning conductors.

Bergman did not draw up any proposals for providing buildings with lightning conductors. As Professor of Chemistry from 1767 onwards, he had a new and large sphere of work, which totally absorbed his energies. It is not absolutely certain when the first lightning conductor was set up in Sweden. According to a compilation of records by Bergman, Strängnäs Cathedral with its high tower was

struck by lightning four times in almost 500 years. Possibly this cathedral was the first building to be fitted with a lightning conductor. The first known sketch of a lightning-conductor installation was made by Wilcke in 1786 in connection with an investigation concerning the protection of the tower of Mariestad church. We have already mentioned a lightning stroke on the church in 1762, a few days after Bergman's visit there. The damage then was very slight and still did not lead to any safety measures being taken. It was probably a quarter of a century before Mariestad church was fitted with a lightning conductor.

Thus Torbern Bergman's lecture did not have any immediate consequences. It was several decades before lightning conductors were installed to any great extent. Many prejudices and the conservatism of the builders had to be overcome. The question of the economical aspect of the matter cropped up. It was cheaper to insure a house against fires caused by lightning than to pay instalments on a lightning conductor (32). But cultural treasures are invaluable and often personal property is invaluable too. In that case finance plays a smaller part and the psychological aspect appears. People have often had lightning protectors installed to gain security in thunderstorms. In this respect women's fears in particular have been an important factor. Television in rural districts has provided new impulses, for a television antenna is, of course, a lightning conductor. New and financially justifiable measures must be investigated (56). In the Swedish countryside lightning conductors are being built today, 200 years after Torbern Bergman's lecture, at one-tenth of the cost of the traditional lightning conductors on the "Do-it-yourself" principle.

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The staff of the Stockholm Stadsmuseet investigated the "Stjernan" house and placed a picture at my disposal (Fig. 15).

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