Volta's Electrophorus – the First Electric Generator?

Translation of a letter dated 21st December 1775 from Alessandro Volta to his friend Canon Francesco Fromond, with introduction and commentary

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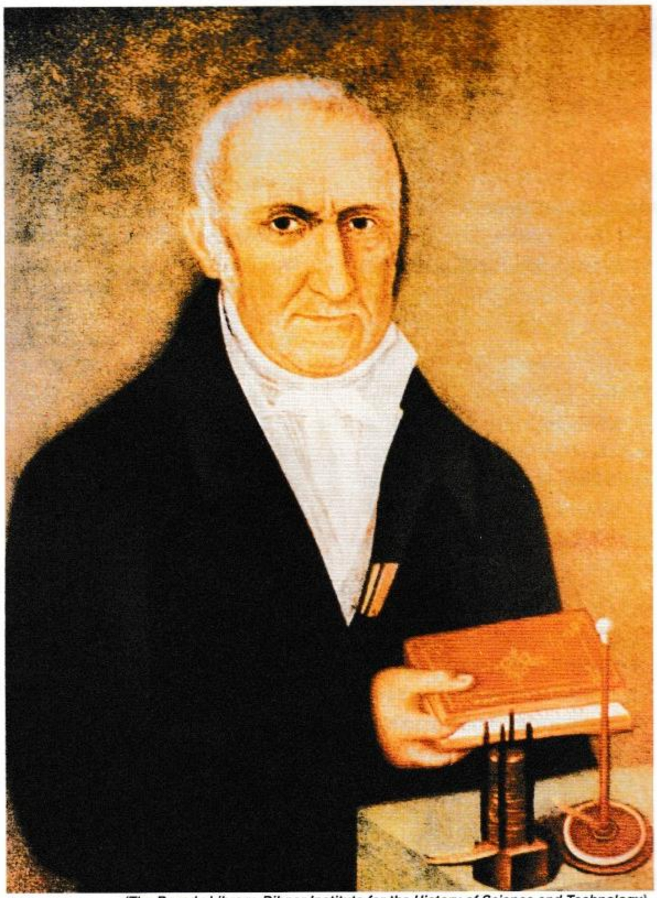
This article reports the first English translation of the letter sent in December 1775 by Alessandro Volta to his friend Canon Francesco Fromond. It is presented here together with a few introductory notes to help the reader to understand better the technical content of the letter, as well as some aspects of the author's personality that clearly emerge from reading his letter.

In this text, Volta discusses some physical phenomena as well as modifications to improve his 'electrophorus', a device that he invented in 1774 and which was first announced in 1775 in a letter to Joseph Priestley. This unique document is now part of the Henry Willard Lende Collection and held in San Antonio, Texas.



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1 ***Alessandro Volta, 1745–1827***

Alessandro Volta and the Science of Electricity

Alessandro Volta was born in the town of Como, in the north of Italy, on the 18th February 1745. He had four brothers, three of whom became priests, and four sisters, two of whom became nuns. His father Filippo had been himself in the Jesuit order for eleven years until, at the age of forty-nine, he decided to marry a girl of nineteen. Filippo Volta was of noble birth but a poor administrator of the family funds, leaving considerable debts on his death.

Alessandro had a peculiar infancy. He was regarded as being slow in learning and indeed mute until he was four years old! At that age, however, his mind ignited and by the time he was seven he had built the reputation of being an extremely bright boy. Thereafter he was very successful at his studies.

Because of the strained circumstances of his family, Volta's education was made possible only by the endeavours of relatives in the church and he was soon under considerable pressure to enter the priesthood himself. He was however extremely curious about natural phenomena and decided at the age of fourteen that he wanted to become a physicist, claiming that there were enough priests and nuns in his family to make it unnecessary that he should try to sanctify it any further!

However, his education and inclinations did not limit his interests to the physical sciences alone. He was also highly literate in classical subjects, up to the point that he indulged in Latin poetry himself. He did so with considerable merit, as he echoed, almost naturally, the great Latin poet Lucretius, who, like him, was also attracted by the power of nature.

As a scientist he was an experimentalist. This is something that this letter shows very well. He was attracted by electricity, or what was known at the time as the 'electric fire'!

At the time of writing this letter, Alessandro Volta was already a successful man. He had been superintendent of the Royal School of Como and was to enter a distinguished career as Professor of Physics at the University of Pavia, thanks to the protection of the Austrian emperor who then ruled the north-east of Italy. He was a handsome, tall and distinguished person who was just as well acquainted with ordinary people as with the foremost men of Europe. He was in contact with the most prominent scientists of the time responsible for advancing the knowledge of electrical phenomena.

Such science was then in its very infancy. The first machine for generating electric charges had been discovered by Otto von Guericke in 1660; he showed that electrical charges could be produced by means of friction. In 1729 it was further discovered that these electrical charges could be transmitted from one body to another through a suitable conductor. Not long after that, the Frenchman Charles Francois de Cisternay Du Fay, noticing that charged bodies would repel or attract themselves, thought that there were two kinds of electricity (in this he was not quite correct) and that like charges repel whilst unlike charges attract.

The Leyden jar had been invented, showing that electrical charges could be stored. Benjamin Franklin – probably the most prominent figure in the theory of electricity at that time – was greatly admired by Volta (who finally met him in 1789). Franklin had realized that the duality of electricity was, in fact, caused by two aspects of the same single force, namely the excess and the deficiency of it. Hence the wording 'positive' and 'negative' was given to these two aspects and various bodies and materials may have been distinguished by their ability to 'give' or 'receive' electricity.

This, therefore, was the background when, in the year 1774, Volta produced his first contribution to this field of science – the 'electrophorus' – which is the subject of this letter.

The electrophorus was a machine capable of producing a replenishable supply of static electricity, the novelty being that the principle of induction was applied rather than the use of direct friction, as had been the case until that time.

The Electrophorus

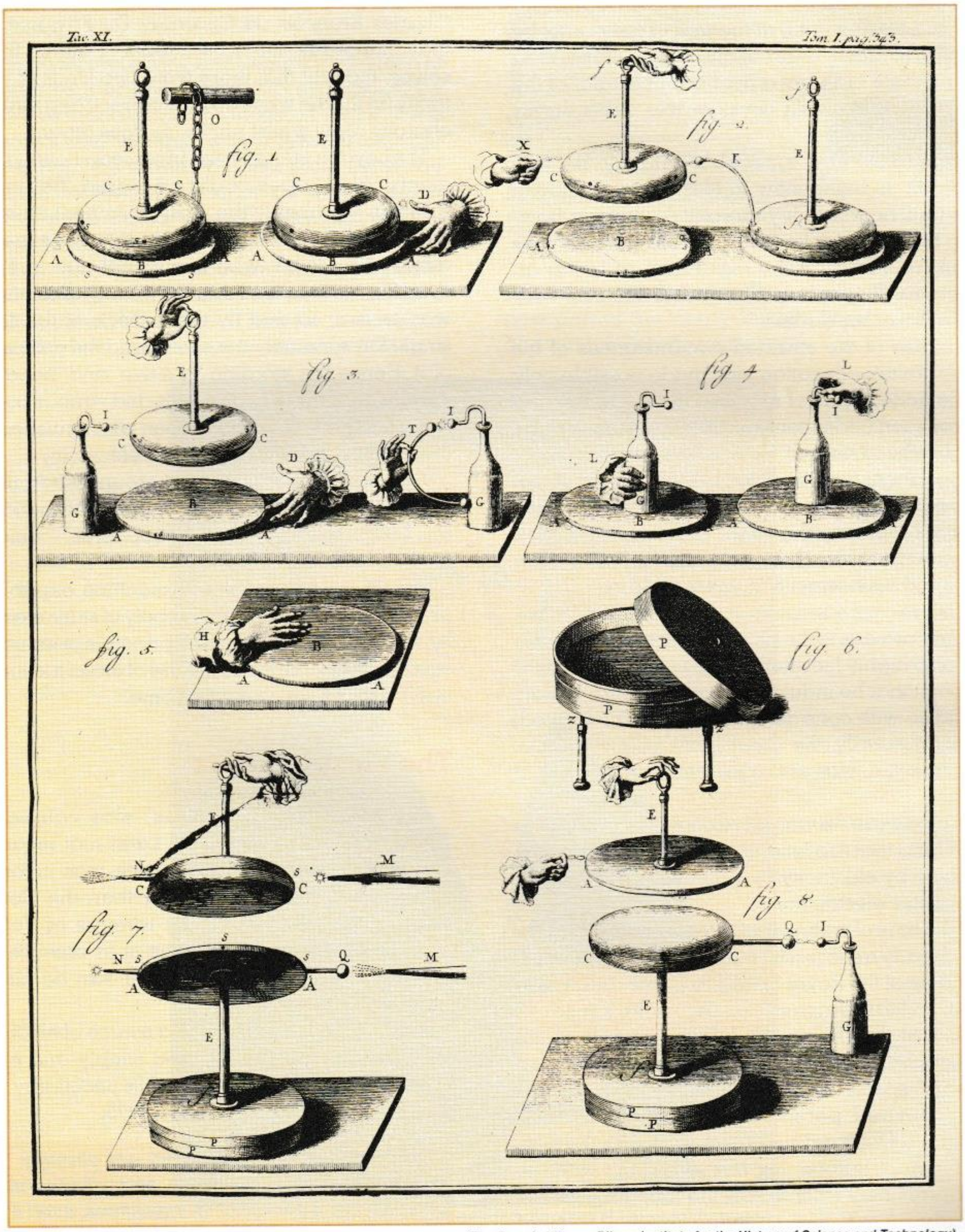
The word 'electrophorus' was coined by Alessandro Volta himself, its Latin root meaning 'carrier of electricity'. The device was invented some twenty-five years earlier than the electric battery, which is the most famous of Volta's inventions. The electrophorus is in essence the precursor of the Wimshurst and Van de Graaff static generators.

It was intended to provide a source of electrical charges which could be used simply and effectively in electrical experiments. Its peculiarity was that, as he wrote to Priestley in 1775:

> *'...electrified only once and not strongly, will never more lose its electricity, and will obstinately maintain the live force of its indications, even if it is touched again and again'.*

Figs. 2 shows its essential parts in its original form and some applications of the apparatus. This consists of a lower (A) and upper (C) metal plates, the latter also being called the 'shield' and equipped with an insulated handle. The plates (A) and (C) are separated by some non-conducting material such as a cake of resin (B).

The machine is operated by first charging with negative charges the upper surface of the resin (B) by means of friction, and then bringing the momentarily-grounded shield (C) in proximity of the charged surface of the resin. Volta used chains or a human finger for touching and grounding the shield.



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2 ***The electrophorus***

The ground contact would allow the electrons to flow through the shield, giving it an opposite charge to that of the resin. This type of charging was to be called 'electrostatic influence' or 'induction'. The machine is in effect a capacitor or condenser operated in this special way. The shield could be carried via its insulated handle and used to charge other bodies.

The charge on the resin does not escape, except at the few high spots where the metal actually touches it and, more generally, through dispersion. In this way the shield could be charged repeatedly, producing an easy source of static electricity.

The letter to Francesco Fromond deals with an improvement to the shield. He writes about the benefits of replacing the metal plate with a waxed canvas wrapped with silver leaf over its frame and upper surface, opposite that directly touching the resin.

Volta also suggests that the lower metallic plate may be replaced with a wooden disc, again covered with silver leaf on the side opposite the resin, in order to avoid direct discharges and to allow a thinner layer of resin.

It should be noticed that the Wimshurst machine and the Van de Graaff generator are, in essence, improvements of the method used for transferring the electric charge so that continuous transfer can be achieved. In both cases this is still done mechanically and without 'flow' of electrons (hence the word 'static generators').

In particular, the Wimshurst machine is very similar to the electrophorus. Here the human action of transferring the metal plates is done automatically by using a rotating disc of glass which carries metal plates past the charged insulated plate, whilst replacing the human finger with a static metal brush for grounding.

Although Volta's electrophorus demonstrated how to generate and transfer electrical charges, it may not be called a true electric generator, because it cannot effectively be used to sustain an electric current in a external electrical circuit. In contrast however, the Wimshurst machine can be used as a generator because of its charge transfer mechanism. The disc can rotate at about 100 r.p.m. when driven by a belt powered by a hand-operated wheel, and hence can produce a few tens of milliamps at about 50 kV. This shows, in essence, the advantage of static generators: generally they are not very efficient at producing large currents, but can instead generate very large voltages – up to 4 MV in the case of a large Van de Graaff machine.

Specific Comments on the Letter

It is worthwhile focusing briefly on the content of the letter. It has essentially three sections: the first is concerned with the description of a new kind of shield *(scudo)*; the second describes the possible use of wood with a metallic layer for the construction of the lower plates, in order to avoid explosive discharges; and the third deals with the possible explanation of a problem caused by some resin *(mastice)* which was interposed between the plates.

However, it is fair to say that from the content of this letter alone, any clear identification of the machine discussed here is difficult. Clearly Fromond knew the subject and this is a working document for him.

As electrical phenomena were not yet fully understood at the time, it is perhaps more interesting to note the explanation of the various effects that Volta gives. They reflect the belief that electrical properties were some kind of intrinsic 'virtues', specific to various materials and bodies, and that the transfer mechanism between them was caused by an 'electric fluid' with bipolar nature. Interestingly, even if some scientific explanations may appear superficial today and certain assumptions are, in effect, wrong or at least very imprecise, Volta nevertheless shows the attitude of the modern scientist; his conclusions and his approach show a methodology which does not differ greatly from that accepted today in modern science.

Volta is a precursor of the 19th Century positivistic philosophy. On one side he trusts the human intelligence and he is well acquainted with the rules of logic that had been described and studied by previous rationalistic and idealistic philosophers and especially by the classic Greek philosophers. He deals with his learning process accordingly, and utilises the so-called phases of induction, analysis and synthesis.

However, rather than pretending to understand the mechanisms of nature only from the results of pure rational thoughts which cannot be questioned as long as proved logically flawless (a successful method in Mathematics for instance), there is here much more emphasis on the importance of the experiment. The purpose of the whole exercise is generally that of achieving a useful and practical result, rather than of mere speculative knowledge.

The overall goal for him is the ability to discover new natural phenomena, as well as the ways for predicting and controlling their outcome. This is done through various steps, involving the conception of an idea (the induction) which is then analysed in detail in order to check whether it is consistent or contradictory. However, it is only the synthetic phase that really matters for Volta: that is, the definition of a proven set of actions and facts that reliably reproduce the desired result.

In the particular case of this letter, this is a method for producing the correct resin, to be used and optimized for the 'electrophorus'. The passages relating to this subject are perhaps even more interesting than the technical content itself.

Translation of a Letter from Alessandro Volta to his Friend Canon Francesco Fromond, Dated 21st December 1775

My dearest Friend,

Como, 21st December 1775

I am sending back to you the pages of the 'Rozier' that were sent to me. Please let me have the others that follow†. Then, in due time, I hope to receive those related to the coming year, the association of which I have found: I now only need to know how, how much and to whom I will have to give the money.

I tried to build the shield, just as I had thought to do, and using a canvas laid down on a frame. I have chosen the waxed canvas, without silver plating on all the waxed side which faces and touches the resin. I was happy just to attach the silver leaf on the side which remains uncovered, as well as on the borders of the frame.

I find that this shield works wonderfully and completely matches my expectations. At first, believing that there was no need to silver plate the side of the canvas that touches the resin, I thought it better to attach the silver leaf only to the borders of the frame, where the sparks are collected.

However, as the waxed canvas acts as a very poor conductor, I soon realized that a canvas of this type could release its native fire only very slowly and with great difficulty, being incapable of meeting the excess fire from the resin or vice versa.

This was clear by noticing that, when the shield was put in position and touched, either using a finger or a little chain, and in particular when touching the silvered border of it, then a small spark could be collected. After a few seconds and touching again, another little spark could be collected, and so on for a few minutes.

If the shield was lifted after having collected such a series of little sparklets, or, if I may say, after having exhausted the charge, then a very large and powerful spark would be released. But if the shield was lifted after having touched the border only once, then the resulting spark was much less powerful.

After noticing this, I then resolved to cover with a silver sheet the whole external side of the waxed canvas. In this way the whole discharge is performed essentially in a single touch and without any limitation caused by the reduced thickness of the canvas which previously created problems because of its large size.

After all, as I repeat, it is certainly useless to give a metallic finish to the side that faces the resin or, if anything, it could be damaging.

In fact, the extreme mobility of the electric fluid in metallic bodies coupled with some small grainy imperfection on the lower side, could easily give origin to some dispersion.

In other words it becomes more likely that the intrinsic electricity of the resin may be transported through such imperfections. This is not the case, however, when employing a nearly coercing surface such as that of the bare waxed canvas.

Furthermore, a shield which does not expose any metal on the surface of the resin, nor threatens to break it or melt it with the spark as it is lifted, also does not easily cause the spontaneous explosion when some breaks occur in the resin as the shield is laid on it and receives the discharge. This is contrary to what usually happens with the shields used until now, as soon as the charge becomes sufficient.

As we are on the verge of suppressing the metallic surface in order to eliminate as much as possible the means for the spontaneous explosions, I must not forget to let you know some of my other observations and advances about the practice and theory of the electrophorus.

As mentioned, I had suspected that there was no need for the resin to be spread over a metal. I said to myself that it may well be good enough to simply spread it over a non-insulating body. Therefore, I tried to pour it over a disc made of wood, as well as over some cardboard.

In fact, I was able to notice that there are signs almost as strong as when a metal dish is used. I only notice that for a large electrophorus made of wood, the discharge can occur only slowly (more or less as I observed in the case of the shield without metal on both sides).

† Volta refers here to the journal 'Annals de Physique', ed. by Rozier.

Therefore the fire that originates from the upper surface, that is, the shield, cannot quickly transfer through the wood which is not very permeable, and transfer itself to the lower side of the resin, and vice versa.

On the other hand, allowing for this to happen, I see that the wood is actually very useful for every effect. It would even be possible to eliminate the defect related to such slow transfer by simply pouring the resin on the top of the wooden plates as done before, but then covering the bottom of them with metal.

Ideally these should be only a few lines† thin. But what about their mechanical strength? It seems to me that such thin slabs arranged in such a fashion, could well be treated just as a single large wooden block and full stop.

Therefore you may ask: what is the advantage of such a complicated arrangement? Is it to allow the resin to be poured over the wood, rather than over a metal? Precisely: since in this way we will not allow the means for the sudden explosions to take place any longer (which is what I proposed to do in the first place); and without the fear of such explosions we may be doing well to lay down a much thinner layer of resin, as this is still a very important factor for the good of the final outcome.

There you have it, my friend, a new suggestion useful for building that tremendous electrophorus that I do wish to see completed. There you have the corrections that I could conceive in respect of both the shield and the plates or discs.

Will these be the last? I do not know. But please do not call them useless because of that: these are still steps that lead to the final result and so far the other modifications were never made without progress.

But what are you doing? Do you think or implement my or your ideas? Why are you not giving me any report, especially concerning yours?

I will not conclude before recalling to you my last thoughts in relation to such a rare phenomenon caused by the resin of that great electrophorus, and in particular the fact that this resin constantly gets charged positively. I am very convinced that you will have not been able to observe a similar thing, no matter how hard you may have tried.

The large or small size of the machine does not have any bearing in the matter. Nor did I wish to imply that the large size may cause the difference. I merely stated that the resin, which showed such a singularity, was that of the large apparatus, regardless of the fact that its composition was the same as the other resins which I used.

† The word 'lines' is a literal translation

Such was the situation as far as the composition and mixing were concerned; but I failed to remember an accident that occurred whilst the resin was being cooked, and that must have altered its properties. The accident was that the resin caught fire and the flames consumed a great deal of it.

What was left was half burnt or contaminated with a coal-like material, so that it now always leaves smears on the hands or on the paper every time it is rubbed. It also crumbles very easily.

Hence, I assumed that such modification, that is the inclination to charge itself with positive electricity, depends on the modified nature of the resin. Gaining more insight in the matter, I started to suspect that such a mutation of nature is caused by the deterioration of the original electrical virtue, or at least it is closely related to it.

In fact, I noticed that this half burnt resin showed very little tendency to charge itself by means of friction, while the others could be reliably charged in such a way, even employing metal plates, and always showing a generous negative charge.

In my view it was very clear that such behaviour was common to other materials that are affected by negative charges no less than the resins. These are the half burnt baths.

I had already noted and written about these in the 3rd chapter of my *'Diss^e Latina 1771'*, that such materials, if fresh and well processed, give to any body, including metals, that have been rubbed against it, until the maximum virtue lasts.

However, as soon as such virtue degrades, then they start to lose also their intrinsic nature and start to receive, first only from a few metals, then from most of them, then from all of them and in some cases even from the black cloth etc. Now I can extend this concept also to the resins.

From one extreme we have the very best resin that collects a good electrical charge by means of only a short and light friction. In the other extreme we have that half burnt resin that, even when rubbed over a surface as large as two feet, as in the case of the great machine, it can only produce a small spark (I point out that this is the case of simple friction which leads to only a small spark that can be collected at the shield. When we impose a greater electrical strength using another machine or bottle*, then the system performs to no less degree of strength than for the case involving the best resin).

Between these two extremes, we have other resins that can get charged relatively well by the rubbing action.

* Literally 'flask' or 'carafe' – probably what is now known as a Leyden jar (invented 1746)

Along with this originating virtue, the resins of the first class influence so thoroughly the negative electricity that they cannot get a positive charge even when the gold paper or other metallic sheets are used: only with the amalgam of mercury can I force them to get charged.

The second, or better the latter resins following their scale of virtue, have completely changed their nature and get charged positively by both metal and any other material.

In the middle, finally, we have resins that give to the hand, bare paper, leather etc., and receive from gold paper, lead leaves etc.

Therefore both the induction and the analysis confirm my suspicion that it is the degradation of the virtue that causes the reversal of nature in resinous bodies.

But do you believe that I could satisfy myself with these arguments? The induction is still too broad and, on the other hand, I wish to have it confirmed with the synthesis.

In other words, I have established nothing until I can process resins with means of distinguishing their quality or their virtues and I can produce them in the way I want, so that I can have from one side a kind of nature and from the other side its opposite.

For the time being, I can say to you that I have tried to work on it and with some success.

As expedient to purposely deteriorating the quality of the resin, I have mixed it with some coal powder. It is well known that coal is a material only slightly less conducting than the metals. Therefore I choose it in its powder form, in order to reproduce the alteration that my resin must have suffered when it was in flame.

The result was that a certain dose of coal mixed with the very best of my resin degraded it considerably. In effect it reduced it to receive from the metallic leaves, to which before it gave.

However, I could not in any way succeed to make it receive from the hand, bare paper, cloth, etc. or in other words, to reverse its nature as in the case of the half burnt resin.

Therefore, I tried to set it on fire and left it to consume for a while. But even in this way I did not manage to succeed. I then increased the dose of coal but now I could not see any sign at all of electrification, neither positive nor negative.

In conclusion, the tests carried out fell short of satisfying me. However, they do not contradict the conceived idea.

On the contrary, I feel that the resin degraded to such an extent that it did not show any visible sign of frictional electrical properties any longer, as it may just have passed the mark that I was looking for.

Or else it could well be that it did not pass it at all and it did charge positively after all, but to such a small extent that I could not appreciate any sensible sign of it.

Such sign may only be significant in cases involving the great machine, because of the very large surface being rubbed.

There you have, my dear friend, my thoughts on the origination of electricity in resins.

How many more trials need still to be done!

For goodness sake, do something more yourself. Some time ago you promised me some amalgamated satin of England: please let me have some. Please give me also some written reports and tell me about the results regarding the electrophorus.

My greetings to Father Campi and to anyone who asks about me. I am

Your Affectionate Friend

A. Volta

Acknowledgement

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Bibliography

DE SANTILLANA, G., 'Alessandro Volta', *Scientific American*, **212**, 1, p. 82–91, 1965.

DIBNER, B., 'Alessandro Volta and the Electric Battery', Franklin Watts, Inc., 1964.