Although the discovery of thermoelectricity is traditionally assigned to Seebeck, it is now well assessed[1] that the very first observation of what is named Seebeck effect was reported by Alessandro Volta in the following letter

Alessandro Volta

New memoir about the animal electricity split into three letters sent to Abbot Anton Maria Vassalli, Professor of Physics at the Royal University of Turin

First letter (from the Physico-Medical Journal of Mr. Brugnatelli, vol. 2, page 248, year 1794)[2]

What do you think about animal electricity? Personally, it has been my opinion for a long time that the whole action proceeds from metals in contact with a wet body or with water; that, as a result of such contact, the electric fluid is pushed into the wet body or into water by the metals, some more, some less (zinc more than any other, while silver to a lesser extent); when a proper, continuous connection is granted, such fluid circularly moves across. Whenever the limb nerves of the frog, suitably cut, or any other nerve ruling the motion of a limb, including that of other animals as long as they retain some vitality, act as connecting rings of such a conduction circuit, in whichever part of it, such that the electric current had to flow through them, either entirely or almost entirely, the muscles and the body parts obeying those nerves then tense so that by closing the conductors, an electric current arises. If, instead of the nerves controlling the motion, the circuit is closed by those serving the sense of taste or of sight, they cause a feeling of taste or of light; such feelings and movements are stronger when the metals are farther away from each other in the following list: zinc, tinned sheets, common tin in plates, lead, iron, brass and bronzes of different types, copper, platinum, gold, silver, mercury and graphite, to which one finally adds some wood coals, namely those that behave almost like metals, as all others either do not work or work poorly.

Of the many ways I carried out such experiments, the following is especially surprising and impressive. Given four or more people, either isolated or even with their feet on the floor, if it is not too wet, let them form a chain with one of them touching with a finger the tip of the tongue of his neighbor, another touching the eyeball of his neighbor, and the last two holding with their wet fingers the feet and the torse of a frog, freshly scraped and sliced open; then, let the first person in the row hold a zinc plate with his wet hand while the last holds a silver plate

[1] L. Anatychuk, J. Stockholm, G. Pastorino, "On the Discovery of Thermoelectricity by A. Volta". Proc. of the 8th European Conference on Thermoelectrics, Como, Italy, 2010, pp. 15-18.

[2] Translation by Dario Narducci. English revision by Megan Rylko and Alexandra Zevalkink.

and have them put the two plates in contact: suddenly, the person holding the zinc plate will feel on the tip of his tongue the taste of acid while the eyes will see a flash of light and the frog legs will tense violently.

Here you then see the electric flux, flowing through the whole chain of persons, and if they wonder whether they do not feel any shock in their arms, etc., it is easy to reply that the current is not large enough to that aim, but it is enough to excite the most sensitive nerves through which the fluid flows in a concentrated way, namely the nerves of taste, which almost lay bare on the tip and the sides of the tongue, those of sight deep in the eye, and the crural nerves of the sliced frog, all located along the path of the electric current, in this experiment.

Now, what is proving *animal electricity*, namely electricity that originates in the body organs, here? Is it not more probable that organs are merely passive, simple, highly sensitive electrometers and that metals are instead active, being the contact among them to provide the impulse that moves the electric fluid; or, in other words, are the metals not only conductors or carriers but also the true engines of electricity? But why do I say probable? It is so evident that everything depends upon metals and their different qualities since the success of these experiments requires two different metals: an absolutely essential condition, indeed. Thus, instead of calling it *animal electricity*, it could be more properly named *metallic electricity*.

And do not object that sometimes movements of the frogs prepared following Galvani are obtained even using metals of the same quality at both sides, namely silver and silver, mercury and mercury, tin and tin, iron and iron. Yes, movements are observed (but not always) at the beginning only, when the small animal, prepared in the best way, is still highly sensitive, reacting even upon tiny stimulation. But how to be sure that the metals used at both sides are exactly the same? Let them be such by name and substance, but accidental qualities of hardness, temper, polishing and surface shine, temperature etc. can make them different enough for the electric action, namely for their capability of pushing the electric fluid into the wet body they are in contact with or to pull it, not so differently from what is observed (as known already from experiments carried out by Canton, Bergmann, Cigna, Beccaria, etc.) when the same metals and other bodies are more or less suitable to generate or accept the electric fire upon friction. It is well proven that of two electric bodies made of the same matter and quality, when rubbed against each other, the roughest or the warmest or that being more damaged by friction *yields* while the other *receives*. Similarly, also a perfect or imperfect conductor, a metal, a stone, a piece of wood, etc. that is rough on one side and polished on the other yields or receives from a silk band, a white paper, a piece of ivory, another piece of wood, etc., depending on the surface finishing, either rough or smooth, on their being warmer or colder, or whether they are rubbed longitudinally or transversally, etc. Thus, I think that also the motion of the electric fluid, occurring either by direct contact or by putting metals in contact with a wet body or with water, with no need to rub them (as proved by recent experiments) might be caused – and more or less enhanced – in a similar way so that the current moves in one or in the other direction as a result of even small differences in the hardness, temper, temperature, polishing, and shine of the two pieces of silver, brass, iron, and lead all believed to be similar and even between the two opposite ends of a bar or of a metal sheet.

However, since I was not satisfied by conjectures, although well based upon good analogies, I wished to verify with an experiment whether and to what extent such accidental qualities impact the action that metals exert on the electric fluid. Having prepared an arc with a thick, unannealed, elastic iron wire, I sunk its ends into two glasses of water where a frog, properly and freshly prepared, was also sunk with its hind legs in one glass and with its back or the spinal cord (if only this was left) in the other glass to see if I could make it contract and jump; I often succeeded at the beginning, namely two, three, or four times but no longer after a few minutes. And I should say that, using different iron arcs, more than one was found unable to cause any effect even at the beginning. The same happened with some silver arcs and with brass arcs as well; they were found fully ineffective. Therefore, it is sensible to think that the ineffective arcs were such because their ends were perfectly equal as of temper and else and, therefore, fully equipollent while this was not the case for other arcs since it is uncommon to find a perfect equivalence. Now, after having found, out of many tests, an iron arc unable to cause any action even at the beginning and after having left the frog relax so that it were no longer excitable not even by those arcs that were initially able to cause its contractions (something that happened very soon), I sunk an arc end in boiling water for about half a minute and then, after extracting it and without letting it cool down, I went back to the previous experiment with the two glasses of cold water; I saw the frog tensing, even repeating the experiment two, three, four times up to when the iron end, cooled down because of the many and repeated submersions or because of its prolonged exposure to air, turned back to be unable to cause animal contractions. Furthermore, if I made an end of the iron arc red-hot so to soften its temper, keeping the other end unannealed, the arc was also able to cause frog contractions even after being cooled down and for long times up to when the animal was much weakened.

From these experiments, it is shown that, if heat by itself does something, the quality of the temper does even more, letting the same metal, namely the two ends of one body when differently annealed, act differently on the electric fluid when in contact with water or with wet bodies, displaying different strengths as if they were two different metals.

I reiterated the same experiments using sheets of brass, silver, and tin, obtaining the same results. The only difference was that, since iron admits more degrees of temper than any other metal, differences of the electric action depending on the temper are much more evident and notable with iron, so one may obtain a larger effect when, in such experiments, one uses iron sheets of different temper instead of two distinct metals with qualities not too far away in the rank of electric power, like gold and silver, copper and brass, brass and iron, or lead and tin sheets.

What more? I found some iron sheets with ends displaying such differences of action, possibly because of their temper or for other reasons, comparable to those met in metals separated by several degrees of ranking such as lead and silver to the point that, as those pairs, they not only cause violent contractions and spasms in frog muscles, even when not sliced but simply scraped, but also a sour taste when touching the tip of the tongue.

Concerning metal polishing and cleaning, I found that, if two pieces of the same lead sheet applied to the frog's back and legs after preparing it properly (i.e., leaving only crural nerves to connect legs and body) do not elicit any muscle contraction or motion, it is enough to scratch one of the two pieces with a pocket knife to give it a mirror shine before applying it again using its new luster surface to obtain the awaited effect. Such a capability vanishes within a short time as soon as its exposure to air makes the surface dull again. Furthermore, if both pieces of lead are made to shine, the experiment fails or is anyway less successful than when one end only is treated.

Anyway, when I carefully prepared both metal parts to be applied to the frog limbs, either directly or through water or wet bodies, in such a way to make them as similar as possible or when I used gold and silver sheets or wires of the same kind on both sides, I almost never saw the frog tense, either when the metals were directly in contact or when an arc of another metal was used, no matter how well the animal was prepared. I say *almost never* to stay on the safe side since sometimes some weak effect was observed, which I ascribe to the imperfect equivalence of the two ends.

After all this, if Galvani or others further state that, at least when two identical metals are found suitable to cause contractions and either strong or weak movements in the frog prepared as he uses, the electric fluid cannot be driven but by the animal organs, and, therefore, a true animal electricity exists, I will object that when such effects are observed, the metals are not truly identical; I will say that that they differ either by their heat* or their temper or their polishing and shine, all facts that I have shown not to be irrelevant, as they lead to differences not less important than using metals of different quality as of their capability to move the electric fluid in water or in touching wet bodies. It is up to Galvani to prove that one cannot find even the smallest difference of those types or of other unknown types that may possibly be relevant; I mean, no difference, either perceivable or imperceivable between the metallic end sunk into one glass and that sunk into the other one or between the ends that are connected to the rear legs of the prepared frog and to the upper part of its nerves or to its body; it is up to him to prove (a rather difficult, not to say impossible, task) such a perfect similarity and identity of the two ends of the metallic arc when they are able to cause contractions without using a different metal while I have already shown that any different quality of the metals, either substantial or accidental, suffices to move the electric fluid, letting it move with such a strength to generate those effects that very similar metals cannot create. Now, if this principle, namely this metallic activity I have discovered and demonstrated, is clearly sufficient, why should one invoke another merely supposed principle, namely that of a natural unbalance of the electric fluid in the animal organs? It would be a useless multiplication of causes to explain similar effects. Let us stick to what is directly and surely proven; do not let us be fascinated by conjectures and hypotheses looking pleasant and attractive but turning out to be vain and useless as they transcend the evidence gathered from the simplest and clearest experiments.