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Volta's Apostle: Christoph Heinrich Pfaff, Champion of the Contact Theory

1. Introduction

During the first half of the nineteenth century, a protracted controversy raged among European natural philosophers concerning the cause of voltaic phenomena. The substance of the controversy was, to put it briefly, whether Volta's pile was a chemical machine or its source was rather to be found in the contact force that Volta had postulated to exist between two dissimilar metals. Although a full analysis of the complex controversy remains to be written, recently the subject has been examined in considerable detail by historians of science.[1] We know what happened, if not always why things happened the way they did.

The purpose of the present paper is not to present once again the details of the controversy, but to discuss the role of one of its most central figures, the German-Danish scientist C.H. Pfaff, a leading expert in electrical science during the first half of the nineteenth century.[2] Christoph Heinrich Pfaff (1773-1852) considered himself the heir of Volta's legacy and remained throughout his life a staunch defender of the orthodox contact theory. In his massive history of electrochemistry, Wilhelm Ostwald characterized Pfaff as "the inevitable" and a "painstaking historian of galvanism and zealous defender of voltaism [who] won special merit particularly in the propagation of the knowledge of galvanic phenomena in Germany".[3]

2. Who was Christoph Heinrich Pfaff?

Pfaff started his scientific training in the Karl Academy, near Stuttgart, where he established a lasting friendship with the four years older Frenchman Georges Cuvier, who would later become a famous pioneer of zoology and paleontology. In addition to the classical languages, he studied medicine, chemistry, physics and natural history at the Academy. As a young man he had a brief flirtation with the

[1] See BAK (1999); KIPNIS (2001); KRAGH (2000).
[2] KRAGH and BAK (2000). See also HUFBAUER (1982), pp. 223-4, 254-5, and PFAFF (1854).
[3] OSTWALD (1980), I, p. 66. Ostwald erroneously gives Pfaff's first name as Christian, a mistake that can be found in other works as well. For Ostwald's work, see MORRISON (1978), pp. 213-25.

then fashionable ideas of *Naturphilosophie*, an influence which was stimulated by the chemist and anatomist Carl Friedrich Kielmeyer, professor at the Karl Academy and a leader of the German school of *Naturphilosophie*. However, Pfaff soon reached the conclusion that science had to build on experimental facts, not on metaphysical systems. Throughout his scientific career, he subscribed to a methodology that can be best described as a version of empirical positivism. His escape from *Naturphilosophie* seems to have been indebted to his correspondence with Cuvier, who had little patience with metaphysics. "I wish everything that experience shows us to be carefully dissociated from hypotheses", Cuvier wrote to Pfaff in 1788; "science should be based upon facts, despite systems".[4]

In 1793, Pfaff graduated from the Karl Academy with a Latin dissertation on animal electricity, the main part of which was published in Gren's *Journal der Physik* the following year.[5] In 1795, an extended and revised version of the dissertation appeared in German.[6] The work was very well received in the scholarly world and immediately made Pfaff's name known to the electrical community of chemists, physicists and pharmacists. Georg Lichtenberg, Samuel Sömmerring, Friedrich Gren and Johann Friedrich Gmelin all agreed that it was a masterly and systematic exposition of galvanic science. According to Lichtenberg, "Among the experiments on so-called animal electricity performed until now, the ones of Dr. Pfaff, a young man with a superior talent for observation, are outstanding".[7] Also Friedrich Schelling, the famous *Naturphilosoph*, was deeply impressed. In 1798, he and Pfaff spent a week together performing galvanic experiments. After his departure, Schelling wrote to Pfaff:

> I will never forget the short time we lived together. The galvanic experiments you showed me have given me several sleepless nights. The force [Kraft] that I glimpse in them astonishes me more and more, the more I think about it. [...] I am convinced that you are fated to truly understand galvanism.[8]

More important than local reception in Germany, the dissertation also caught the attention of Volta and thus served to change the course of Pfaff's scientific life. From 1795 to 1798, Pfaff continued his studies in medicine, physics and chemistry, mainly in Göttingen and Copenhagen. On one of his journeys, accompanying a Danish nobleman and his family on their stay in Italy, he had the opportunity to pay a visit to Galvani in Bologna. In 1798 Pfaff obtained a chair at the Christian-Albrecht University in Kiel, the capital of Holstein and at the time part of the Danish empire. Replacing Johann Gottlieb Schrader, an older supporter of the

[4] Quoted in BOURDIER (1970), p. 522. See also BEHN ed. (1845) and KANZ (1993): Kanz provides further references to Pfaff's published correspondence with, among others, Schelling, Hegel, Goethe, Kielmeyer, and his brother Johann Friedrich Pfaff, a mathematician.
[5] See PFAFF (1793).
[6] See PFAFF (1795).
[7] Quoted in TRUMPLER (1992), p. 100. Trumpler's dissertation includes a careful analysis of Pfaff's work.
[8] Schelling to Pfaff, March 6, 1798, as quoted in TRUMPLER (1992), p. 101.

Aristotelian conception of chemistry, Pfaff introduced the new, anti-phlogistic chemistry at the University of Kiel. Three years later, he met Volta in Paris, with the result that he instantly converted from galvanism to voltaism (see next section). Pfaff soon became recognized as one of the world's leading experts on galvanic and voltaic phenomena, an area of science that experienced a phenomenal growth during the first three decades of the century. The growth may be illustrated by Johann Gehler's authoritative *Physikalisches Wörterbuch*. Whereas the 1798 edition included no entry on "galvanism" (and, of course, none on "voltaism"), the revised edition of 1828 covered the subject in great detail. Pfaff, who had become co-editor of the volumes that appeared between 1825 and 1844, wrote about galvanism on nearly 600 pages.[9]

Pfaff remained throughout the rest of his life a professor in Kiel, where he expanded the scientific institutions and served as President (*Rektor*) of the University. Although his main contributions to science lay within the fields of galvanism and voltaism, he was busy also with other branches of science. For example, he wrote one of the first "histories" of electromagnetism and was instrumental in introducing to German-speaking scientists Faraday's new method of generating electricity by means of induction. In addition to his works in physics, he did important work in chemistry and pharmacy, including an investigation with Justus von Liebig on the chemical composition of caffeine.[10]

Pfaff was not a great innovator or a very original scientist, but his work was nonetheless of great significance, particularly in his role as a propagator and organizer of science in Northern Europe. He had excellent connections with a large number of the period's most important scientists and corresponded or had personal contacts with giants such as Cuvier, Dumas, Ørsted, Volta, Lagrange, Ohm, Liebig and Faraday. Fluent in German, English, French, Italian and Danish, he served as an important link between the Northern and Southern regions of European scientific life. His role in Danish science has been underestimated, probably because the University of Kiel is traditionally considered a German rather than a Danish university. (After the Prussian-Danish war of 1864, Holstein became part of Germany). Yet Pfaff was a central figure of Danish and Scandinavian science, and for a period his laboratory in Kiel was the best equipped physical and chemical laboratory in the kingdom. Among his Danish students was the chemist Johann Georg Forchhammer, who would later become Ørsted's assistant and subsequently professor of mineralogy and geology at the University of Copenhagen.

3. From Galvanist to Voltaist

Pfaff's name was already known to Volta before the two met in Paris in 1801. Volta was aware of Pfaff's dissertation, to which he referred in letters to Francesco Mocchetti in the summer of 1795 and also in a letter to Friedrich Gren of August

[9] PFAFF (1828), pp. 554-1011.
[10] For references, see KRAGH and BAK (2000).

1796.[11] In 1801, when Volta's discovery made headlines in Europe, Pfaff happened to be in Paris on a study tour supported by the Danish government. He studied chemistry with Antoine Fourcroy, Claude Berthollet and Louis Thénard, and was particularly interested in the latest progress in pneumatic chemistry. It was here, on an October day in Fourcroy's laboratory, that he witnessed one of Volta's celebrated demonstrations of the pile. In his dissertation, Pfaff had been critical of both Galvani's theory of animal electricity and Volta's metallic theory, but the meeting with Volta caused him to change his mind. The young scientist was instantly captured, not only by the marvelous pile but also by Volta's personality. From Paris, he wrote to a friend in Copenhagen:

> The last weeks of my stay here have been infinitely interesting to me. I see Alexander [*sic*] Volta daily. Everything about the galvanic phenomena is now clear to me. Volta has described his most recent experiments and explanations in a couple of important memoirs, of which he has informed me of in handwritten form; together with an account from the Commission of the National Institute, which has been appointed to investigate galvanism, I will make these publicly known.[12]

Half a century later, Pfaff looked back on his meeting with Volta as the happiest moment of his life. He referred to the Italian scientist as a "wonderful man" in whose personality was united "modesty, such a large measure of honesty, and so many different qualities".[13] Volta's modesty seems to have impressed his young admirers in Paris. Thus, the theme entered prominently in a letter to Pfaff from Michael Friedländer, a German physicist with whom Pfaff had stayed in Paris. Writing shortly after Pfaff's departure, Friedländer referred to his "happiness" of being together with Volta, whose work he did not hesitate to compare with Benjamin Franklin's.[14] Among electricians at the time, to be called "a second Franklin" was the highest praise possible.

On his side, Volta held the young and ambitious German natural philosopher in high esteem. For example, in a letter to Martinus van Marum of 1801 he referred to Pfaff as "a highly esteemed German scientist, an eminent cultivator of physics, natural history, and chemistry, and the author of works that are much to his honor".[15] Indeed, Pfaff concentrated instantly and enthusiastically on Volta's discovery and became one of its main prophets in German-speaking Europe. In 1801, he published no less than fourteen papers on the subject in German and Danish journals. Many of these appeared in *Nyt Bibliothek for Physik, Medicin og Oeconomie*, a journal in Danish language that was founded in 1801 as a

[11] *VO*, I, pp. 347, 361 and 418. On Volta and Pfaff, see WIEDEMANN (1986-7), pp. 39-48.
[12] PFAFF (1801), pp. 155-8.
[13] PFAFF (1854), p. 133.
[14] Friedländer to Pfaff, December 15, 1801, in *VO*, IV, p. 219. Friedländer lived in Paris from 1800 to his death in 1824. He wrote one of the earliest accounts of German research on the voltaic pile. See FRIEDLÄNDER (1801), pp. 101-6.
[15] Volta to Martinus van Marum, in *VE*, IV, p. 73.

continuation of an earlier one.[16] Other papers appeared in *Nordisches Archiv für Natur- und Arzneywissenschaft*, a Danish but German-language journal that Pfaff founded and edited (1799-1805) together with Poul Scheel, a Danish physicist; still other accounts were published in *Französische Annalen für die allgemeine Naturgeschichte, Physik, Chemie, Physiologie und ihre gemeinnützigen Anwendungen* (1802-3), a short-lived journal edited by Pfaff and Friedländer. In 1802, Pfaff wrote a longer, authoritative article in Gilbert's *Annalen der Physik*[17] and also visited Brussels, apparently on Volta's invitation. "The famous professor Pfaff from Kiel" lectured on Volta's explanation of the pile and performed a series of experiments in front of the Belgian audience.[18]

Yet Pfaff was not satisfied with his activity. He wanted to write the big, authoritative work on voltaic phenomena. As he explained to van Marum: "I am working at present on a complete treatise on galvanism, in which I shall assemble in systematic order all the really authentic facts, and in which I shall reduce them to the laws of electricity".[19] Volta knew about Pfaff's ambitious project and urged him to go ahead. On January 23, 1802, he wrote to Pfaff:

> I am very much pleased with your idea of publishing a treatise which presents everything that has taken place concerning galvanism, and to put this matter in the clearest light; no one else can do it better than you. The works you have done several years ago, [and] the order and method that govern them, prove it.[20]

At the time, Pfaff and van Marum collaborated in Leyden in proving the identity of voltaic and frictional electricity, a work Volta followed with great interest. In a letter to van Marum, Volta described Pfaff as "the apostle of my doctrine", a label that the German scientist was only proud to accept.[21]

Further proof of Volta's appreciation of Pfaff is included in a letter of 1803 to Ludwig Wilhelm Gilbert, the editor of *Annalen der Physik*. Referring to his meeting with Pfaff in Paris, Volta wrote:

> We often met, and I explained to him in great detail the electrical theory of my apparatus. He grasped it completely and went into all of my ideas to such an extent that he should be capable to account for this theory even better than I can. – Why doesn't he publish something more comprehensive about it? The article he published in your journal several

[16] *Physicalsk, Oeconomisk og Medicochirurgisk Bibliothek* was founded in 1794 as a journal devoted to Lavoisier's new chemistry. It continued, under different names, until 1806. A small group of Danish scholars and electrical enthusiasts published their voltaic studies in this and other journals. Apart from Pfaff and Ørsted, the group included T. Buntzen, A.W. Hauch, J. Saxtorph, P. Scheel and H. Steffens. For the significance of the journal, see BOSTRUP (1996), which includes a bibliography of thirty of Pfaff's publications between 1800 and 1806.

[17] PFAFF (1802).

[18] The lectures were reported in VAN MONS and GÉRARD (1802).

[19] Pfaff to van Marum, January 8, 1802, in LEFEBVRE and DE BRUIJN eds. (1976), p. 277.

[20] The letter, originally in French, is quoted in WIEDEMANN (1986-7), p. 43.

[21] Volta to van Marum, March 3, 1802, in *VO*, IV, p. 215. The Pfaff-van Marum collaboration was published as PFAFF and VAN MARUM (1802).

> months ago is excellent, but too concise, and several of your German authors seem not to have been converted by it.[22]

There is little doubt that Volta saw in Pfaff a prophet who could "convert" German scientists to the contact theory, and that Pfaff happily accepted the role as preacher and apostle. This is also what we learn from Gilbert many years later. In an editorial introduction to one of Pfaff's papers, Gilbert wrote that Pfaff "had worked meticulously in the new field of physics [and] with such excellent results that Volta, whom he met in Paris, entrusted him with advertising and cultivating his theory in Germany".[23]

4. A Brief Outline of the Voltaic Controversy

The essential question behind what soon became known as the voltaic controversy was this: what was the ultimate cause of the pile? Was it a chemical machine – working only because of chemical processes between metal and liquid – or was it operated by the contact force between dissimilar metals that Volta had postulated even before his invention of the pile? This is not the place to repeat the details of the exceedingly long and complex controversy, which has been described elsewhere in the literature (see notes 1 and 3). What matters here is only Pfaff's role in the controversy, which was squarely on the side of the voltaic contact explanation and against the competing "chemical" view. He first attacked the chemical theories in 1814, when he criticised works by Davy, Berzelius and others, and in the late 1820s he became engaged in a major battle with the Geneva scientist Auguste de la Rive, a main protagonist of the chemical cause.

At that time the contact theory was generally accepted, not least in German-speaking Europe. One of the few adherents to the chemical theory, the Finno-Russian scientist Georg Friedrich Parrot, wrote bitterly that after Volta's experiments in Paris, "all the physicists embraced the hypothesis with ardent zeal". He continued: "In Germany, there was something of a propaganda campaign to disseminate it [Volta's theory], of which C.H. Pfaff was the self-proclaimed champion. The chemical theory of the pile was eclipsed".[24] Yet in 1829, with the first works of Antoine-César Becquerel and de la Rive, the chemical theory was ready for a come-back. Realising the danger from the reborn chemical theory, Pfaff summarised his many arguments and experiments in favour of the contact theory in a major book on "galvano-voltaism" published in 1837.[25] He believed, mistakenly, that the book would settle the matter and put an end to the controversy.

The controversy sharpened during the late 1830s, when Michael Faraday entered the debate on the side of de la Rive and his allies. We may get a glimpse of the debate about 1840 from a letter Faraday wrote to de la Rive this year:

[22] January 10, 1803, in *VE*, IV, p. 236.
[23] PFAFF (1821).
[24] PARROT (1829), p. 47.
[25] PFAFF (1837).

> For a long time I had not made up my mind: then the facts of definite electrochemical action made me take part with the supporters of the chemical theory; and since then Marianini's paper, with reference to myself, has made me read & experiment more generally on the point in question. [...] I enter under your banner as regards the origin of electricity or of the current in the pile. My object in experimenting was, as I am sure yours have always been, not so much to support a given theory as to learn the natural truth and having gone to the question unbiassed by any prejudices I cannot imagine how anyone whose mind is not preoccupied by a theory or a strong leaning to a theory can take part with that of contact against that of chemical action.[26]

Faraday's main contribution to the debate was his long and seminal paper "On the Source of Power in the Voltaic Pile" in which he provided a wealth of experimental data against the contact theory; moreover, he also argued that the theory was "improbable" and theoretically unsound because "were the contact theory true, then, as it appears to me, the equality of cause and effect must be denied".[27] Phrased slightly anachronistically, Faraday claimed that the contact theory violated the principle of force conservation.

Although Faraday's forceful arguments proved important in the long run, they did neither decide the controversy nor convert the remaining contact theorists to the cause of the chemical theory. Pfaff was unimpressed and continued his fight against the chemical challenge. In 1841, after having experimented with his own version of a Grove cell, he reported euphorically to his friend Ørsted in Copenhagen:

> I hasten to inform you of an experiment entirely decisive for the theory of voltaism, definitively silencing the long fought struggle over the source of electricity in the closed chain, and completely ensuring the triumph of the contact theory. [...] Could there be a more vindictive proof of the contact theory and against the chemical theory? [...] This experiment, truly an Experimentum crucis, does not leave any more escapes for the chemical theory.[28]

However, Pfaff was soon forced to realise that his conclusion was wishful thinking. Neither this nor other of his experiments were of the decisive nature that both he and his opponents were so much occupied with.

Given Faraday's statement in his letter to de la Rive, it is interesting to note that Pfaff did not find his British colleague to be "unbiassed by any prejudices". On the contrary, he suspected Faraday to be biased and his experimental results to be influenced by his wish to prove the chemical theory. In his last major work on the Volta pile, the 72-year-old Pfaff wrote:

> As a staunch defender of Volta's contact theory of the galvanic chain I found myself doubly challenged [...] to check with the utmost impartiality Faraday's reasons. [...] I soon realized that Faraday, in his polemics against Volta's views, had not done the matter

[26] Faraday to de la Rive, April 24, 1840, in WILLIAMS ed. (1971), pp. 369-70 ("Marianini's paper" was "Sulla teoria degli elettromotori, memoria IV," *Memorie di Matematica e Fisica della Società Italiana delle Scienze*, 21 (1837), pp. 205-46). Marianini was in favour of a modified contact theory which did not presuppose the two metals to be in close contact.
[27] FARADAY (1965), II, § 2072.
[28] Pfaff to Ørsted, January 19, 1841, in HARDING ed. (1920), p. 474.

> full justice, and that he maintained the chemical theory with a kind of passion and endeavoured to secure its triumph; for this reason I became suspicious [and doubted] if all of the new experiments reported by Faraday were correct.[29]

It can of course be questioned who was most biased, Faraday or Pfaff. Faraday could rightfully have countered that Pfaff was not, to quote from his letter to de la Rive, a scientist "whose mind is not preoccupied by a theory or a strong leaning to a theory".

5. A Note on Terminology

A series of galvanic chains or elements made up a pile (or battery), which was seen as an apparatus producing enhanced galvanism. Although the term "galvanism" originally referred to animal electricity, after about 1796 – and especially after 1800 – it came increasingly to signify electrical phenomena associated with circuits of chains consisting of dissimilar metals and a humid conductor. The change in meaning reflected the victory of Volta's view over that of Galvani, but Galvani's name continued to be commonly associated with both simple chains and the compound pile. After 1800, the older name "galvanic chains" were often termed "voltaic chains," without any distinction being made between the two terms. They were used interchangeably and independently of whether the author subscribed to the contact theory or not.

The somewhat confusing terminology appears, for example, in Pfaff's detailed descriptions in the revised edition of Gehler's *Wörterbuch*. Here, the pile was described mainly under two different headings, namely "On the Enhanced Galvanism, or the Galvanic Action in the Multiple Chain" and "Pile. The Voltaic or Galvanic Battery".[30] Whereas Pfaff followed most other electricians in not distinguishing between Volta and Galvani when writing about the pile, he suggested a difference between the associated words "Galvanism" and "Voltaism":

> The phenomena which manifest themselves in this manner [in the pile] make up, more precisely, enhanced galvanism, the multiple chain, or so-called voltaism. The latter term has been suggested in memory of the immortal inventor of the pile and as being different from galvanism, which more precisely denote the phenomena associated with the simple chain.[31]

Yet, not even Pfaff was consistent in his use of the terms galvanism and voltaism. As mentioned, in his main work of 1837 he preferred the hybrid name "galvano-voltaism". Although Galvani's name thus continued to be commonly used throughout the controversy, some advocates of Volta's theory felt initially that a new terminology was needed, one that reflected the decisive break that had occurred with the invention of the pile. After all, this was Volta's invention, not Galvani's. In a letter to Adam Wilhelm Hauch, a Danish nobleman and gentleman scientist, Pfaff wrote from Paris: "After all what has happened, I believe that it is

[29] PFAFF (1845), p. III.
[30] GEHLER (1828), p. 824 and (1836), p. 1.
[31] *Ibid.* (1828), p. 825.

now time to abandon the names galvanism, galvanic fluid [and] galvanic phenomena, and to give the beautiful investigations made by Volta – whom I admire as another Franklin – their due".[32] Pfaff did not follow his own suggestion, but in his early works he preferred the voltaic term "metallic electricity" to the more common "galvanic electricity". The change in terminology pleased Volta, who in his letter to Pfaff of January 23, 1802, wrote: "I have been very much interested (because it serves science to remove and banish errors) in abolishing the word galvanism. The term metallic electricity, which you have chosen, is the same one that I have adopted for a long time".[33]

It is, finally, worth discussing briefly whether the term "voltaic controversy" is at all an appropriate one. The reason is that almost all the experiments in the protracted controversy were made with simple galvanic chains rather than with the voltaic pile. In most cases, it simply was not necessary to build up a pile in order to investigate whether the action was caused by chemical or contact forces; two metals and a humid conductor would do. As Pfaff pointed out, "all the phenomena of the enhanced galvanism [i.e., the voltaic pile] can be looked upon from the same rules that I developed for the phenomena of the simple chain".[34] Nonetheless, the experiments with the galvanic chains were always seen as connected with and referring to the voltaic pile; they were only considered significant if they could be related to the pile. Volta's pile was unquestionably at center stage in the controversy. For this reason it is justified to refer to the voltaic controversy rather than, say, the controversy over the galvanic chain.

6. Concluding Observations

Among the many features of the voltaic controversy that deserve attention is the disciplinary relationship of the controversy, that is, how it related to the growing separation between physicists and chemists that occurred during the decades when the controversy was at its height. Since the controversy was between a chemical and a physical explanation of the pile, one might believe that it included a disciplinary component with chemists being in favour of the chemical theory and physicists defending the contact theory. However, that would be to read too much into the term "chemical". Although the majority of the contactists were what can be called physicists (with the danger of understanding the term anachronistically), there were also chemists defending Volta's theory.[35] More importantly, the main protagonists of the chemical theory, Becquerel, de la Rive, and Faraday, were primarily physicists rather than chemists. As far as Pfaff is concerned, he probably would refrain from classifying himself as either a physicist or a chemist. He was a chemist,

[32] PFAFF (1801), p. 146.
[33] WIEDEMANN (1986-7), p. 43.
[34] GEHLER (1828), p. 824.
[35] See KRAGH (2000).

a physicist, a medical doctor, a pharmacist – in short, a natural philosopher or a scholar within the *Naturlehre* tradition.

As Stuart Strickland has argued, galvanism (and voltaism as well) played an important role in the reconfiguration of the scientific disciplines at the end of the eighteenth century and the beginning of the nineteenth century[36] Volta was not himself interested in the chemical effects of his invention, and yet it was these effects that attracted most interest in the early part of the nineteenth century. To a certain extent, Volta's pile was seen as a chemical invention, with great consequences for the science of chemistry. As noted by Strickland, many histories of galvanism, written during the early part of the nineteenth century, saw the post-Volta development as essentially belonging to chemistry. "In a word," wrote Johann Trommsdorff in 1803 in his *Systematische Handbuch der gesammten Chemie*, "galvanism now crosses over completely into the territory of chemistry".[37] However, to use Pfaff as an argument for the appropriation of voltaism under chemistry, as Strickland does, is hardly justified. Pfaff did certainly not consider the Volta pile to be a chemical phenomenon, nor did he see its value as exclusively, or just mainly, related to chemistry. It is also noteworthy that whereas the early phase of the voltaic controversy received much attention in chemical journals, from about 1825 the controversy was mostly discussed in journals of physics.

Almost the entire voltaic controversy was concerned with producing experimental evidence and qualitative explanations. Hypothetical-deductive methods and mathematical representations were rare, although not completely absent.[38] The work involved in the controversy illustrates what Kenneth Caneva has called "the science of the concrete", that is, a conception of the nature of knowledge that rested on supposedly decisive, qualitative experiments.[39] Physical knowledge, according to this conception or tradition, was direct, visualizable (*anschaulich*) and demonstrative. It is noteworthy that both sides in the controversy adopted this conception of "concretizing science". One might believe that the contact theorists, many of them physicists, were less biased toward experimental reasoning and more in favour of an abstract conception of knowledge, but this was not generally the case. The predilection with crucial experiments was shared by the voltaists and the "chemists" alike. Indeed, Caneva singles out Pfaff, the main advocate of the contact theory, as a typical representative of concretizing science.

Pfaff firmly believed in Volta's contact theory and had no doubt that it could be convincingly demonstrated by a few crucial experiments. In this respect, he was no anomaly. De la Rive, Faraday and other advocates of the chemical theory were no less occupied with crucial experiments that would instantly show the superiority of

[36] STRICKLAND (1995). On the role of voltaic phenomena, and electrical research in general, on the transformation of German physics – and, by implication, chemistry – see also JUNGNICKEL and MCCORMMACH (1986), pp. 34-45.
[37] Quoted in STRICKLAND (1995), p. 460.
[38] The main exception was Jean Baptiste Biot's electrostatic theory of Volta's pile. See BROWN (1969).
[39] CANEVA (1978).

their favoured theory. The problem was only that none of the many proclaimed crucial experiments were *de facto* crucial, that is, they failed to settle the matter in a clean and unambiguous way.

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