ØRSTED, RITTER, AND MAGNETOCHEMISTRY

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1. INTRODUCTION

Magnetochemistry is the study of the effect of magnetic fields on chemical reactions. The subject received its name in the early 20th century[1] but the search for such an influence began one century earlier. In the very beginning of the 19th century, after the invention of Volta's pile and before the discovery of electromagnetism, several researchers were looking for effects of magnets on chemical reactions. One of the reasons behind this search was the evident analogy between electricity (or galvanism) and magnetism. Volta's pile and magnets have opposite poles that exhibit attraction or repulsion. Were there any other equivalent properties? As Volta's device could produce chemical effects, several authors expected to find similar influences of magnetism. However, as this paper will attempt to show, there were other grounds for this investigation.

One of the researchers who reported chemical effects produced by magnets was Johann Wilhelm Ritter. His claims were announced by his friend Hans Christian Ørsted, who seemingly accepted his ideas and experimental results. However, other researchers could find no such effect, and Ritter's findings were soon discredited. After the discovery of electromagnetism there arose a new wave of positive reports concerning chemical effects of magnetism, but doubts were again cast on those effects. For several decades there was a disagreement between experimental reports and it was not altogether clear whether a magnet could indeed incite any chemical change.

[1] The earliest book on this subject was probably Edgar Wedekind's *Magnetochemie*, published in 1911. Although the name "magnetochemistry" was not used in the early 19th century, we can use it without fear of the terrible charge of anachronism, because we find it in Lorentz Oken's *Lehrbuch der Naturphilosophie*: "Magnetism and chemical action [*Chemismus*] are the main generating agencies for the solid nucleus of the Earth, which is build by both of them. The process of constructing the Earth is a magneto-chemical one." Lorentz Oken, *Lehrbuch der Naturphilosophie* (Jena: Friedrich Frommann, 1831), p. 139. Notice that Lorentz Oken, or Ockenfuß (1779–1851) was a naturalist who embraced the philosophical school created by Schelling. He held the chair of Medicine at the University of Jena and published in 1809–1810 the first edition of his work *Lehrbuch der Naturphilosophie*, where he stressed the importance of polarity and the unity between galvanism and the vital force. I am grateful to Dr. Andreas Kleinert for calling my attention to this book.

R. M. Brain, R. S. Cohen and O. Knudsen (eds.),
Hans Christian Ørsted and the Romantic Legacy in Science, 339–385.

This paper will present the early history of magnetochemistry, during the first three decades of the 19th century, with special emphasis on Ritter's work and Ørsted's involvement with this subject. This particular episode will then be discussed in the framework of the philosophical context of that time. It will be shown that there was a strong influence of Schelling's *Naturphilosophie* upon Ritter's and Ørsted's early views on this subject and that Ritter's search for magnetochemical effects cannot be understood without taking into account this philosophical basis.

I. EXPERIMENTAL MAGNETOCHEMISTRY

2. THE EARLIEST REPORTS ON MAGNETOCHEMISTRY

Electricity and magnetism exhibit several well-known similarities. They can act at a distance, and both can produce attraction and repulsion. It was natural to think that there could be a deeper relationship between them, and towards the end of the 18th century this led the Bavarian Academy of Science to propose the following prize question (1774–1776): "Is there a true physical analogy between electric force and magnetic force?" The result of the competition was published in Van Swinden's book, *Analogie de l'éléctricité et du magnétisme*, where one can find descriptions of the magnetic effects of thunderbolts side by side with curious experiments, such as G. W. Schilling's claim that eels are attracted by magnets.[2] Also recall that, around this time, Franz Anton Mesmer's demonstrations of "magnetic" phenomena upon human beings was very influential for several years and helped to direct the attention of the researchers to the relations between life and physical forces.

After the discovery of galvanism, attempts were made to find fresh correspondences between magnetism and the new phenomenon. According to Pierre Sue, Richard Fowler observed around 1796 that a magnet could induce muscular contractions, but afterwards he noticed that the same effect occurred with a non-magnetic iron bar.[3]

In 1797 Alexander von Humboldt (1769–1859) published his book *Über die gereitzte Muskel- und Nervenfaser*, where he presented and discussed several galvanic phenomena. Among them, he referred to some experiments made by Ritter, who excited contractions in frogs with magnets.[4] He produced a galvanic arc with two pieces of iron and observed no twitching of the frog. He replaced one of the iron pieces by a magnet and there was an immediate twitching of the frog. He also used a chain with iron and steel and observed no effect, but when the iron or steel piece was connected to a magnet, there were strong effects. "Both experiments prove sufficiently that the magnetic steel in the galvanic chain works differently from steel or iron. This confirms Ritter's experiments."[5] Other effects

[2] J. H. Van Swinden, *Analogie de l'éléctricité et du magnétisme ou récueil de mémoires, couronnés par l'Académie de Bavière,* 3 vols. (La Haye/Paris: La Compagnie/Veuve Duchesne, 1785), vol. 1, p. 436.

[3] Pierre Sue, *Histoire du galvanisme et analyse des différens ouvrages publié sur cette découverte, depuis son origine jusqu'à ce jour,* 2 vols. (Paris: Bernard, an X [1802]), vol. 1, p. 207.

[4] Ritter did not publish any account of his early work on this subject.

[5] A. von Humboldt, *Versuch über die gereitzte Muskel- und Nervenfaser*, 2 vols. (Posen: Decker und Compagnie, 1797), vol. 2, p. 189.

were however difficult to explain. When he used two similar strong magnets, no twitching occurred when the unequal magnetic poles were attached to one another, but there were contractions when the equal magnetic poles were in contact and, in this case, there was no heterogeneity that could explain the effect.

In the French translation of Humboldt's work, published two years later, he denied any direct influence of magnetism upon galvanism, but then adds: "We have certainly the right to think, according to very strong analogies, that even a weak magnet, when it is put close to a living animal or vegetable, changes the effects of its vitality and produces the acceleration of its nutrition, the general motion of fluids and other vital functions."[6]

Humbolt's views about the relation between electricity and magnetism was inconstant. He denied that the nervous and magnetic forces were of the same nature, but accepted that magnetism can influence several physiological phenomena. He admitted that Mesmer's "magnetic" phenomena could be spurious, but that "we cannot infer from this that the application [of hands] do never produce physical effects."[7] He also wrote:

> It seems that the animal fibers have a property analogous to that of a magnet. In the dance of Saint Gui, the contracted muscles loosen as soon as they are touched with an iron bar. Other metals are as ineffectual as glass or wax, as reported by Scherer. This is an important discovery; but we should not conclude from this that it is the magnetic force which moves the muscles.[8]

At some places, he returns to the idea of a fundamental unity between galvanism, electricity, and magnetism:

> Perhaps the galvanic, electric and magnetic fluids have many mutual connections and only differ from one another as blood, milk and the juices of the plants, for instance. It may occur that the galvanic, electric and magnetic phenomena do not depend on particular substances, but only on the special proportions in the parts that constitute the animal body.[9]

In 1800, Ludwig Achim von Arnim[10] published a paper on magnetism where he referred to Ritter's experiments and tried to observe chemical effects of magnetism. Arnim reported that the two magnetic poles exhibited different oxidation phenomena. Arnim covered the two poles of a magnet with iron caps ("armatures"), and noticed that when they were moist, the North pole of the magnet and the armature at the South pole suffered a stronger oxidation. This difference in oxidation seemed to him to explain Ritter's observation that two iron needles would produce

[6] A. von Humboldt, *Expériences sur le galvanisme et en général sur l'irritation des fibres musculaires et nerveuses*. Traduction de l'allemand. (Paris: Didot jeune, 1799), p. 115.

[7] Humboldt, *Expériences sur le galvanisme*…, p. 529.

[8] Humboldt, *Expériences sur le galvanisme*…, pp. 453–454.

[9] Humboldt, *Expériences sur le galvanisme*…., p. 454.

[10] Karl Joachim ("Achim") Friedrich Ludwig von Arnim (1781–1831) studied natural sciences in Halle and Göttingen and medicine in Jena. He became a physician but never pursued this job. He was later to become a famous writer of the Romantic school. He is known for the volumes *Des Knaben Wunderhorn* (The Boy's Magic Horn), published in 1806–1808, containing 600 folk songs he collected with his friend Clemens Brentano (1776–1842). This work strongly influenced the Grimm brothers (Jacob and Wilhelm) who began collecting folktales after reading their book. Arnim also published historical novels, such as *Owen Tudor* (1809) and *Isabella of Egypt* (1812).

galvanic effects. There are other curious effects described by Arnim. For instance: he reported that upon magnetisation the North pole of an artificial magnet becomes heavier, and the South pole becomes lighter.[11]

The relation between oxidation and galvanic effects had already been ascertained by several researchers and was discussed in Arnim's next paper. Trial and error had shown that different metal pairs produced different galvanic effects. In the case of a silver-zinc pile the zinc pieces soon became oxidised, while silver exhibited little oxidation. It was soon suggested that the galvanic effect of a metal pair depended on their different oxidation properties. In order to obtain the strongest effect, the two metals had to exhibit the largest possible difference in their affinities for oxygen. Accordingly, several authors presented lists of metals disposed in the order of their oxidation, and the farther were the metals in the list, the stronger was supposed to be the effect of the pair. Arnim presented his own list where he emphasised that the opposite poles of a magnet exhibited different oxidation: gold—silver—mercury—copper—brass—tin—lead—iron—magnet—pyrolusite—zinc.[12]

According to Arnim, a magnet would suffer stronger oxidation than iron. The two poles, however, would suffer different effects. He reported that the difference in oxidation of the two poles of a magnet was clearly seen when it was put in an infusion of cress seeds. In a single night the South pole became black, while the North pole would remain bright.[13]

Although he did not attempt to produce a Voltaic pile using magnets, this possibility was clearly implied by his analysis and comments on the different properties of the opposite magnetic poles. Following Arnim's work, August Friedrich Lüdicke (1748–1822) attempted to build a battery using a series of magnets.[14]

Lüdicke remarked that the substances of electricity and galvanism seemed the same, because both can be conducted and stored in the same bodies. The magnetic substance, on the other hand, behaves in a different way, and therefore one should hardly expect that magnetic batteries would work.[15] Without any strong expectation, however, he made a trial. He used 50 pieces of magnetic iron. The "friendly" (that is, opposite) poles of successive pieces were put in contact to one another, with pieces of paper wet in salt water between them.[16] The extremities of this pile were put in glass tubes, connected through a vessel full of water. The experiment began at 7 o'clock in the evening. One hour later Lüdicke observed eight very small bubbles at the North pole, and no bubbles at the South pole. Two hours later, there were 11 bubbles at the North pole and only two small bubbles at the South Pole. This showed the stronger chemical effect of the North pole.[17] Notice that Arnim had observed a stronger oxidation at the South pole, instead.

[11] Ludwig Achim von Arnim, "Ideen zu einer Theorie des Magneten," *Annalen der Physik* 3 (1800), pp. 48–64, at p. 59.

[12] Ludwig Achim von Arnim, *Bemerkungen über Volta's Sauele, Annalen der Physik* 8 (1801), pp. 163–196, 257–284, at 279.

[13] Ibid.

[14] August Friedrich Lüdicke, *Versuche mit einer magnetischen Batterie, Annalen der Physik* 9 (1801), pp. 375–378.

[15] Ibid p. 375.

[16] Ibid pp. 376–377.

[17] Ibid p. 378.

In 1802 William Nicholson reported in his *Journal of Natural Philosophy* that a correspondent (Brunn) informed him that "at Vienna[18] a discovery has been made, that an *artificial magnet*, employed instead of a Volta's pile, decomposes water equally well as that pile and the electrical machine; whence (as they write) the *electric* fluid, the *galvanic* fluid, and the *magnetic* fluid are the same."[19] Nicholson added a footnote describing that he tried the experiment but was unsuccessful. He used five bar magnets in series. Their extremities were attached to iron wires that were put in the water, and he "perceived no effect."

A few months later, Lüdicke published another paper.[20] Using a larger number of magnets he obtained irregular effects. With cold water there occurred no bubbles, and with warmer water sometimes there were more bubbles at the North pole, and at other times there were less bubbles at this pole. He also remarked that using twice the number of magnets there was only a very small increase of the effect, and that it was impossible to notice any difference between the oxidation of the opposite polar surfaces. He concluded: "Thus I assume that these connected magnetic pieces may have worked here probably only as good heat conductors, and not by a kind of Galvanism."

3. RITTER'S MAGNETOCHEMICAL EXPERIMENTS

In 1803, Ritter returned to the study of magnetism. His experiments were published by his friend Ørsted, who was then in France. Ørsted recalled that "the phenomena of magnetism have frequently been compared with those of electricity, and many facts seem to justify the comparison", but he remarked that up to that time the facts had been inconclusive.[21]

> Mr. Ritter's first experiments with the magnet concerned frogs. He found that a magnetic iron wire produced, with another non-magnetic wire, a galvanic palpitation in these animals. He noticed that the South pole produced stronger palpitations than the non-magnetic iron, and that the North pole excited weaker ones. Having always noticed that the metals that underwent stronger oxidation produced more powerful palpitations, he concluded that the South pole had a stronger affinity for oxygen than iron, and that the capacity of oxidation of the North pole was lower than that of iron.[22]

Ritter tested this conclusion by submitting a magnetised iron wire to weak nitric acid. According to Ørsted's account, he noticed that the South pole was much

[18] Maybe he was referring to Lüdicke's experiments, but Lüdicke did not work at Vienna, but at Meissen.

[19] William Nicholson, "Scientific news," *Journal of Natural Philosophy, Chemistry, and the Arts* [series 2] (1802), pp. 234–236, at 234.

[20] August Friedrich Lüdicke, "*Fortsetzung der Versuche mit verbundnen Magnetstählen, und ein paar Bemerkungen zu Volta's Sauele,*" *Annalen der Physik* 11 (1802), pp. 114–119.

[21] Hans Christian Ørsted, "*Expériences avec la pile électrique faites par M. Ritter, à Jena; communiquées par M. Ørsted,*" *Journal de Physique, de Chimie, d'Histoire Naturelle et des Arts* 57 (1803), pp. 401–405, at 406.

[22] Ibid. p. 406. Cf. Hans Christian Ørsted, "Experiments on magnetism; by Mr. Ritter, of Jena. Communicated by Dr. Ørsted, of Copenhagen," *Journal of Natural Philosophy, Chemistry, and the Arts*, 8 (1804), pp. 184–186.

more strongly attacked than the other one by the acid.[23] It was soon surrounded by a larger oxide deposit than the North pole.[24] He made other experiments comparing the speed of oxidation of three iron wires—two of them being magnetized and the other one non-magnetic. The South pole began to exhibit oxidation before the others, and next the non-magnetised iron, and at last the North pole. It seems that it was not easy to reproduce this experiment:

> This experiment requires much care. The surface of the water should be covered with fresh almond oil, to avoid the admission of air. It is also necessary to avoid exposing to sunlight one of the flasks more than the others.[25]

The different chemical reactions could also be observed by the use of an infusion of litmus [*tincture de tournesol*]. The water became acid as the iron wires were oxidized, and this could be seen by observing the colour of the solution. The South pole produced a stronger red colour than the other wires, showing that it was undergoing a stronger oxidation. The effect, however, was very weak, and it was necessary to wait for more than 8 days to notice the colour change. It was advisable to add some acetic acid to the water, in such a way that the litmus infusion would be close to the point of changing from blue to red. Contact between the water and air could destroy the effect.[26]

Ritter also attempted to build a battery with magnets. He used 120 magnetised iron wires in series, with opposite poles close to one another but separated by a globule of water. However, the arrangement did not produce the expected effects, but Ritter did not regard this negative result as a refutation of his guiding hypothesis: "However, the clever author did not abandon his hope for composing a magnetic battery."[27]

In December 1805 Ritter presented to the München Academy of Sciences a new paper where the equivalence of electricity and magnetism received an ostensibly full confirmation. He reported that he had finally succeeded in building a magnetic battery that could produce the same effects as a voltaic battery.

His main results were:

1. Each magnet is equivalent to a couple of heterogeneous metals. The different poles are respectively associated to the two dissimilar metals.
2. Consequently each magnet, like these metals, produces electricity. One of the poles gives positive electricity, and the other one negative electricity.
3. A series of magnets also constitutes in analogous circumstances a voltaic battery, as a series of pair of different metals; and in this manner the author

[23] The converse influence of chemical attack upon magnetism had been reported by Tiberius Cavallo, who claimed that after iron was attacked by acids it had a stronger effect upon a magnetic needle: Tiberius Cavallo, "Magnetical experiments and observations," *Philosophical Transactions of the Royal Society of London* 76 and 77 (1785 and 1786), pp. 62–80, 6–25. Afterwards Ruhland reported a similar effect: Reinhold Ludwig Ruhland, *Vermischte Bemerkungen electrischen und magnetischen Inhalts, Journal für Chemie und Physik* 11 (1814), pp. 16–25.

[24] Ørsted, *Expériences avec la pile électrique*…, pp. 406–407.

[25] Ibid p. 407.

[26] Ibid p. 407.

[27] Ibid pp. 408–409.

demonstrated, by means of the electrometer, the electricity produced by the poles of this series of magnets.

4. With this power the battery of magnets exercises upon living or inanimate bodies, the same effects as a voltaic column of equal strength.[28]

> These experiments demonstrate that, in magnetised iron, the South pole yields positive electricity, and the North pole the negative. On the contrary, in the magnetised steel, the north pole yields positive electricity, and the south pole yields negative. The same inverse distribution is observed in the influence of magnetic polarity upon oxidation of the magnetised body. In iron, the South pole undergoes stronger oxidation, and the North pole a weaker one. In magnetised steel, on the contrary, the North pole undergoes stronger oxidation, and the South pole a weaker effect.[29]

The Italian translator of the letter reporting Ritter's results (who was probably Carlo Amoretti, the editor of the journal), added a note commenting that there was also an electric and magnetic polarity in fruits and seeds. The part of the seed where the roots are to appear has positive electricity, and the opposite part is negative. When a pine cone was suspended by a silk thread, inside a glass container, it would turn when a magnet was approached. The South pole of the pine cone corresponded to the part where the roots would appear upon germination. However, when the pine cone was stripped of its hard sheath, this side behaved as the North pole.

It is likely that many researchers unsuccessfully attempted to repeat several of Ritter's experiments, but no public criticism had come to light. In 1807, however, Ritter's work met severe disapproval. Paul Erman (1764–1851) published two lengthy papers, where he presented a detailed experimental criticism of Ritter's work. There were several points under attack: Ritter's work on atmospheric electricity and the *aurora borealis*; his claims concerning the electrical poles of the Earth; the attraction between a silver-zinc needle and a magnet; and the influence of magnetism upon chemical reactions. Contrary to the previous reports of other researchers, Erman found no difference in oxidation between the North and South poles of several magnets.[30] None of his replications of the earlier experiments was successful, and he concluded that Ritter's claims were groundless.

Erman was a respected physicist, and his papers represented a serious challenge to Ritter's claims. Erman's work was not disputed. It helped to bury magnetochemistry for several years, together with other results reported by Ritter.

[28] [Anonymous]. *Extrait d'une lettre écrite de Munich au Prof. Pictet sur quelques expériences galvanico-magnétiques, faites récémment par Mr. Ritter, Bibliothèque Britannique, ou Recueil. Sciences et Arts* 31 (1806), pp. 97–100. This notice was reproduced in a number of journals: [Anonymous]. *Aus dem Intelligenzblatte der Allgem. Litterat. Zeit. Den 5ten Febr. 1806, Annalen der Physik* 22 (1806), pp. 223–224; "Extract of a letter to professor Pictet, from a Correspondent at Munich, upon some galvanico-magnetic experiments recently made by M. Ritter," *Philosophical Magazine* 25 (1806), pp. 368–369; *Estrato d'una lettera scritta da Monaco in Baviera al Sig. Prof. Picted di Ginevra su alcuni sperimenti galvanico-magentici fatti recentemente dal Sig. Prof. Ritter, Nuova Scelta d'Opuscoli* 1 (1806), pp. 334–336.

[29] Ibid.

[30] Paul Erman, *Beitraege über electrisch-geographische Polaritaet, permanente electrische Ladung, und magnetisch-chemische Wirkungen*, *Annalen der Physik* 26 (1807), pp. 1–35, 121–145, at 141–142.

4. MAGNETOCHEMISTRY AFTER THE DISCOVERY OF ELECTROMAGNETISM

In 1820 Hans Christian Ørsted published his discovery of the magnetic effect of galvanic currents, and this finding produced abundant progeny.[31] Some of the works that followed Ørsted's—such as Ampère's researches on electrodynamics and Seebeck's discovery of thermoelectricity—are well known. Some others have not been incorporated into mainstream science and have been forgotten.

Soon after the announcement of Ørsted's discovery, Dominique François Arago reported that an iron wire wound around a cylinder and connected to a galvanic apparatus produced strong magnetic effects. It immediately occurred to Augustin Fresnel that an inverse effect could also exist: perhaps a magnet could produce a voltaic current in a metallic wire coiled around the magnet. His first trials seemed to manifest positive results: the end of the wire that he expected to become positive underwent strong oxidation in water, while the other end suffered no oxidation for several days. He was therefore persuaded that magnetism had produced a voltaic current and a chemical effect. Hence, on the 6th November he presented the confirmation of his conjectures to the French Academy of Sciences.[32] After a few weeks, as further experiments did not confirm his earlier findings, Fresnel concluded that the effect did not exist.[33]

One week after Fresnel presented his first results, C. J. Lehot claimed that he had already discovered the same effect six years before.[34] He reported that an iron wire connected to the South pole of a magnet suffered much stronger oxidation in water than another similar wire attached to the North pole. The different chemical effects of the North and South poles could also be observed by the colour of a litmus infusion, which became red around the wire connected to the South magnetic pole. Lehot recalled that those experiments had already been made 20 years earlier by Ritter, and that they were cited in several works on galvanism.

Soon afterwards, John Murray presented to the Royal Society of Edinburgh a paper where he described some chemical effects of magnetism. Among other phenomena, he described that magnetism would produce the reduction of silver and

[31] Hans Christian Ørsted, *Experimenta circa effectum conflictus electrici in acum magneticum* (Hafniae: Schultz, 1820).

[32] Augustin Fresnel, *Note sur des essais ayant pour but de décomposer l'eau avec un aimant*, *Annales de Chimie et de Physique* [series 3] 15 (1820), pp. 219–222. Ten years later, after the discovery of electromagnetic induction, Ampère suggested that Fresnel's experiment could have exhibited the effect of induced currents. Of course, the motion of magnets would produce only short-lived currents, but he thought that the continuous temperature changes of the magnets that must have occurred during those long-term experiments could produce significant currents. Antoine César Becquerel and Edmond Becquerel, *Traité de l'électricité et du magnétisme et des applications de ces sciences a la chimie, a la physiologie et aux arts*, 3 vols., (Paris: Firmin Didot, 1855–1856), vol. 1, p. 384.

[33] Yelin repeated Fresnel's experiments and could not observe any positive effect, either: Ritter von Yelin, *Ueber den Zusammenhang der Electricitaet und des Magnetismus, Annalen der Physik* 66 (1820), pp. 395–411.

[34] C. J. Lehot, [*M. Lehot adresse une lettre relative à l'expérience dont M. Fresnel a rendu compte à l'Académie dans la dernière séance*]. *Annales de Chimie et de Physique* [series 3] 15 (1820), pp. 406–408.

its precipitation in the form of small crystals. A non-magnetic steel wire, put in a solution of silver nitrate, produced no chemical change, but when it was attached to the north and south poles of two magnets, it soon became covered with crystals of silver. When a magnet was put in the solution of silver nitrate, "the North pole became instantly studded with brilliant pallets of silver, and formed more rapidly and more copiously round it than round the south pole."[35]

New reports continued to appear. In January 1821, Ørsted's friend Christopher Hansteen wrote a letter to Ludwig Wilhelm Gilbert (the editor of the *Annalen der Physik*) describing experiments that had been made a few years earlier by Hans Henrik Maschmann and himself concerning the chemical effects of magnetism.[36] Maschmann, a chemistry professor at the university of Christiania, in Norway, observed in 1817 that the crystallisation of silver (forming Diana's silver tree) from a solution of silver nitrate under the influence of metallic mercury was stronger to the North side of the glass tube he used, and conjectured that the effect could be due to the magnetic field of the Earth. Several later experiments, using both the magnetic field of the Earth and the influence of nearby magnets confirmed that the formation of Diana's tree was faster under the influence of the North magnetic pole. He interpreted the chemical effect as due to galvanism, and concluded that galvanism and magnetism were identical. He also conjectured that magnetism could have some effect in geological phenomena.[37]

Maschmann communicated his discovery to his colleagues Hansteen and F. Keiser—who confirmed his findings—and also to Ørsted.[38] Notice that this happened three years before the discovery of electromagnetism. Hansteen, on the other hand, declared that he wrote a paper on those experiments and sent it to Ørsted in 1819, but the paper was not returned.[39]

A few years later Maschmann's and Hansteen's papers were translated into French, when the Abbot Louis Rendu reported other chemical effects of magnetism. Together with those articles there appeared a paper by Ørsted where he described Ritter's experiments on the chemical effects of magnets.[40]

Any well informed scientist, at that time, would become aware of the existence of several phenomena exhibiting a relation between magnetism and chemistry, and there were many clues pointing out that Ørsted and Ritter had something to do with that subject.

[35] John Murray, "On the decomposition of metallic salts by the magnet," *London, Edinburgh, and Dublin Philosophical Magazine* 58 (1821), pp. 380–382, at 381.

[36] Christopher Hansteen, *Wiederholung und bestätigung der Versuche durch Hrn. Prof. Hansteen, Annalen der Physik* 70 (1822), pp. 239–242.

[37] Hans Henrik Maschmann, "*Einwirkung des Erdmagnetismus auf Auscheidung des Silbers*," *Annalen der Physik* 70 (1822), pp. 234–239.

[38] Ibid p. 238.

[39] Hansteen, *Wiederholung unt bestätigung der Versuche*…, p. 241.

[40] Louis Rendu, *Influence du magnétisme sur les actions chimiques*, *Annales de Chimie et de Physique* [series 3] 38 (1828), pp. 196–197; Hans Christian Ørsted, *Experiénces de Ritter, analysées par M. Ørsted*, *Annales de Chimie et de Physique* [series 3] 38 (1828), pp. 197–200. This paper was a partial reproduction of an article published by Ørsted 25 years earlier, but the journal did not inform the readers about that.

5. DIANA'S SILVER TREE

As described above, one of the claims published in the following years was the influence of magnetism upon Diana's silver tree.

The reduction of metallic salts in aqueous solution produce in special circumstances metallic crystals that build up a treelike (dendritic) structure. This kind of phenomenon had already called the attention of alchemists, who described the so-called "Diana's tree" (*Arbor Dianæ*), built up of silver crystals:

> The Reign of the Moon lasts just three weeks; but before its close, the substance exhibits a great variety of forms; it will become liquid, and again coagulate a hundred times a day; sometimes it will present the appearance of fishes' eyes, and then again of tiny silver trees, with twigs and leaves. Whenever you look at it you will have cause for astonishment, particularly when you see it all divided into beautiful but very minute grains of silver, like the rays of the Sun. This is the White Tincture, glorious to behold, but nothing in respect of what it may become.[41]

In the early 19th century it was found that electricity may quicken the precipitation of those "metallic trees." The "tree of Saturn" can be produced when a copper wire attached to a zinc plate is put inside a diluted solution of neutral lead acetate. Lead precipitates in the form of small bright plaques attached to the wire, and new crystals form upon the first ones, building a treelike framework that gradually grows in the containing vessel.[42] This effect was discovered by William Cruickshank, who conjectured that hydrogen produced by the Voltaic decomposition of water could reduce metals.[43] He described that in the case of silver nitrate the metal precipitated in the form of small needle-like crystals building up Diana's tree. In the same year, Richard Kirwan conjectured that crystallisation could be due to magnetic force.[44]

Independently, Ritter had also noticed that Volta's pile could produce metallic "vegetations" similar to Diana's silver tree. The negative galvanic lead was able to reduce several metals from their salt solutions to metallic crystals, and sometimes the metal crystals gather as the branches of a tree.[45]

As described above, Maschmann, Hansteen, and Murray had claimed that a magnet could have an effect on the formation of Diana's tree. However, shortly after the publication of Murray's paper it was criticised by an anonymous

[41] This book of Eirenaeus Philalethes was first published as *Introitus apertus ad occlusum regis palatium* (Amsterdam, 1667) and translated as *Secrets reveal'd: or, an open entrance to the shut-palace of the king* (London, 1669). The complete electronic text of this book can be found on the Internet, in two different versions: at http://clairvision.org/EsotericKnowledge/Alchemy/Hermetic_Museum/Open_Entrance.html and also at http://www.levity.com/alchemy/openentr.html. The citation was taken from the first electronic version.

[42] Becquerel and Becquerel, *Traité d'électricité et du magnétisme*, vol. 2…., pp. 196–197.

[43] William Cruickshank, "Some experiments and observations on galvanic electricity," *A Journal of Natural Philosophy, Chemistry, and the Arts* [series 1] 4 (1801), pp. 187–191. This paper was translated into German as *Versuche und Beobachtungen ueber einige chemische Wirkungen der galvanischen Electricitaet, Annalen der Physik* 6 (1800), pp. 360–368.

[44] Richard Kirwan, "Thoughts on magnetism," *A Journal of Natural Philosophy, Chemistry, and the Arts* 4 (1801), pp. 90–94, 133–135.

[45] Hans Christian Ørsted, *Ueber der neuesten Fortschritte der Physik, Europa. Eine Zeitschrift* 1 (1803); reproduced in Kirstine Meyer (ed.), *H.C. Ørsted, Scientific Papers* (Copenhagen: Andr. Fred. Høst & Søn, 1920), vol. 1, pp. 112–131, at 117.

author.[46] "B. M." repeated all experiments described by Murray. He reported that he observed no sensible difference between the influences of magnetic and non-magnetic steel in the precipitation of silver.

Murray replied and strongly protested against the anonymous attack: "If *truth* be the object of this writer, why does he blush to own [his name]? Is science to be a masquerade, and its friends appear in false or fictitious characters? An honest man ought to be ashamed of such a contemptible subterfuge […]."[47] He conjectured that the steel used by "B. M." could be slightly magnetic, because the only test that "B. M." had applied was to check whether it attracted iron filings, and that test was not very sensitive. He also claimed that a magnet could precipitate silver from a solution of silver acetate, and that iron could never produce such an effect. "B. M." answered to Murray's reply, but did not comment on the two relevant points of Murray's reply.[48]

Murray's paper produced some polemical papers in Italy, too. Ridolfi reported that he could not repeat Murray's results, and recalled that two other physicists (Catullo and Fusinieri) had also disconfirmed those experiments. However, two other researchers, Nobili and Merosi, claimed that they had successfully repeated Murray's experiments.[49]

Maschmann's and Hansteen's experiments were successfully repeated by Johann Schweigger, who was studying a new kind of metallic "vegetation" produced by the reduction of copper solutions: the "Venus tree" or *Arbor Veneris*.[50] He observed that the metallic tree grew larger towards the North. According to him, Döbereiner also obtained positive results similar to those reported by Maschmann and Hansteen.[51]

In the same year, Karl Kastner also reported that the reduction of metallic salts was stronger towards the North. Friedrich Dulk, however, was unable to observe any influence of magnetism on the growth of Diana's silver tree.[52]

6. OTHER POSIVE RESULTS AND CRITICISM

It seems that Ørsted's demonstration that an electric current produces a magnetic effect led many authors to believe that all electric and magnetic phenomena were equivalent. The Abbot Louis Rendu published a paper where he claimed

[46] B. M. "Observations on Mr. Murray's paper on the decomposition of metallic salts by the magnet," *The Annals of Philosophy* [ser. 2] 3 (1822), pp. 39–41.

[47] John Murray, "Reply to B. M.," *The Annals of Philosophy* [ser.2] 3 (1822), pp. 121–123, at 121.

[48] B. M., "An answer to Mr. Murray's 'Reply'," *The Annals of Philosophy* [ser. 2] 3 (1822), pp. 384–385.

[49] C. Ridolfi, *Lettera all'editore dell'Antologia, Antologia* 7 (1822), 498–501.

[50] Johann Salomo Christoph Schweigger, *Ueber Cohäsion, in Abhaengigkeit von krystall-elektrischer Anziehung, Journal fuer Chemie und Physik* 44 (1825), pp. 79–86, at 81. Notice that Schweigger is also classified as a Romantic physicist: see Walter Kaiser, "Symmetries in Romantic physics," in Manuel G. Doncel, Armin Hermann, Louis Michel, & Abraham Pais (eds.), *Symmetries in Physics (1600–1980)* (Barcelona: Universitat Autònoma de Barcelona, 1987), pp. 77–92.

[51] Ibid p. 85.

[52] Karl Wilhelm Gottlob Kastner, *Zur Geschichte des Galvanismus*, *Archiv fuer die gesammte Naturlehre* 6 (1825), pp. 442–452, at 450; Friedrich Philipp Dulk, *Ueber die chemische Einwirkung des Magnetismus*, *Archiv fuer die gesammte Naturlehre* 6 (1825), pp. 457–467.

that crystallisation was an electrical phenomenon and called the attention to the similarity between needle-like metallic crystals produced in electrolysis and the arrangement of iron filings submitted to a magnet.[53] Guided by this analogy, Rendu attempted to produce chemical effects attaching iron wires to the poles of a magnet.[54] He used a V-shaped glass tube filled with a blue tincture of red cabbage, and introduced the iron wires in each of the branches of the tube. In about 15 minutes the liquid had turned green. It was known that acids would turn this tincture red, and alkalis would turn it green.[55]

Rendu communicated his result to Biot, who conjectured that the effect might be due to a chemical reaction of the iron, instead of a magnetic effect. He suggested to Rendu a new experiment that excluded chemical reaction between iron and water. The iron wires were enclosed in thin glass tubes, closed at its ends, and therefore did not touch the liquid. In the modified experiment the tincture did again become green, as in the former case, but only after 2 hours. Rendu remarked that the tincture turned red, not green, when left to itself.[56]

Rendu's experiment, communicated to the Paris Academy of Sciences by Biot, called again the attention of researchers to the relation between magnetism and chemical reactions. Karl Kastner reported that he also observed an effect of magnetism on vegetable tinctures and on the crystallisation of metals in saline solutions.[57]

In Italy, the priest Francesco Zantedeschi repeated Ritter's experiments and reported that a steel needle attached to the North pole of a strong magnet underwent faster attack in acidulated water than another steel needle attached to the South pole. According to this author, the effect depended on the position of the magnet: it was stronger when the North pole pointed to the North or to the West.[58] This author claimed that in some of his experiments the magnet became weaker after producing chemical effects.[59] He also reported that a copper wire attached to the opposite poles of a magnet and connected to a multiplier (an early type of galvanometer) exhibited an effect corresponding to an electric current.[60] Gustav Wetzlar, however, could observe no influence of magnetism upon the reduction of copper sulphate by iron.[61]

[53] Louis Rendu, "*Observations qui tendent a prouver que la cristallisation de tous le corps est un phénomène électrique*," *Bibliothèque Universelle des Sciences, Belles Lettres et Arts. Sciences et Arts* 38 & 39 (1828), pp. 304–17, 58–72, at 310–311.

[54] Louis Rendu, *Influence du magnétisme sur les actions chimiques*, *Annales de Chimie et de Physique* [series 3] 38 (1828), pp. 196–197.

[55] Rendu, *Observations qui tendent a prouver*…, p. 314

[56] Rendu, *Influence du magnétisme*…, p. 197.

[57] Karl Wilhelm Gottlob Kastner, *Chemische Gegenwirkung des magnetischen Eisens. Nachtrag zum Vorhergehenden, Archiv fuer gesammte Naturlehre* 15 (1828), pp. 336–344.

[58] Francesco Zantesechi, *Nota sopra l'azione della calamita e di alcuni fenomini chimici, Biblioteca Italiana o sia Giornale di Letteratura, Scienze ed Arti* 53 (1829), pp. 398–402, at 400.

[59] Ibid p. 401.

[60] Ibid p. 402. A few years later Zantedeschi was to claim that he had discovered electromagnetic induction before Faraday: Francesco Zantedeschi, *Relazione delle principali scoperte magneto elettriche* (Verona: Antonelli, 1834) (Opuscoli Fisici di Varii Autori, vol. 1, n. 36).

[61] Gustav Wetzlar, *Ueber den elektrodynamischen Zustand, welchen Eisen und Stahl durch Beruehrung mit saurer salpetersaurer Silbersloesung oder reiner Ammoniakfluessigkeit erlangen, Journal fuer Chemie und Physik* 56 (1829), pp. 206–227.

After several authors had reported positive findings, the Leipzig physicist Otto Linné Erdmann attempted to ascertain whether those chemical effects of magnetism did really exist. He used very strong magnets and repeated every kind of experiment that had been previously described. He noticed that several influences could affect the observed phenomena, and stressed that it was necessary to repeat many times each experiment, in different circumstances.[62] He noticed, for instance, that the same iron wire, cut into several pieces, exhibited points where oxidation was stronger or weaker, although they seemed exactly alike in all respects. Contact of the wires with the experimenter's hands or with different substances also affected their attack by water and mild acids.

Erdmann tested several reported effects:

1. the influence of terrestrial magnetism on the oxidation of non-magnetic iron wires;
2. the differential oxidation of the poles of magnets and magnetic iron;
3. the influence of the terrestrial magnetic field on the building of Diana's and Saturn's trees;
4. the influence of magnets on the same phenomena;
5. the change of colour of vegetable tinctures by magnetic action.

In a large series of experiments, taking care to avoid spurious influences, Erdmann could observe no positive effect of magnetism in any of those chemical reactions. He concluded that former researchers who had reported positive effects had been mistaken.

Abstracts of Erdmann's paper soon appeared in French and in English.[63] As had happened in the case of Paul Ermann's 1807 paper, his experiments seemed convincing and were cited by several authors as a definitive proof that magnetism had no influence on chemical phenomena.

7. AFTERMATH

In 1831 Jacob Berzelius described Erdmann's researches and remarked that he had also looked for chemical effects of magnetism many years before (in 1812), but obtained only negative results.[64]

In 1834, in his treatise on electricity and magnetism, Antoine César Becquerel supplied a short review of this subject. He regarded Erdmann's researches as conclusive

[62] Otto Linné Erdmann, *Versuche ueber den angeblichen Einfluss des Magnetismus auf chemische Wirkungen und auf den Krystallisationsprocess, Journal fuer Chemie und Physik* 56 (1829), pp. 24–53, at 34.

[63] Otto Linné Erdmann, "*Expériences sur l'influence presumée du magnétisme sur les effets chimiques et la marche de la cristallisation*", *Bibliothèque Universelle des Sciences, des Belles-Lettres et Arts. Sciences et Arts* 42 (1829), pp. 96–103; Erdmann, "On the supposed influence of magnetism in the phenomena of chemical combinations and crystallizations," *The American Journal of Science and Arts* 18 (1830), pp. 395–397.

[64] Jons Jacob Berzelius, *Jahresbericht ueber die Fortschritte der physischen Wissenschaften*, 30 vols., (Tuebingen: H. Laupp, 1822–1851), at vol. 10, pp. 42–43.

and denied the existence of chemical effects of magnetism.[65] Moreover, the 8th edition of the *Encyclopaedia Britannica*, after describing several experiments made by Ritter, Fresnel, and Maschmann, presented this final comment "Mr. Erdmann, after a very elaborate inquiry into the effects of magnets as chemical agents, came to the conclusion that the observed phenomena were due to the influence of other causes, which had not been sufficiently guarded against."[66]

Not every author concluded that Erdmann's researches were conclusive. In 1843 Leopold Gmelin, in his famous *Handbuch der Chemie,* presented a roll of authors who defended the existence and another list of those who denied the phenomenon, but did not state his own opinion.[67] Again and again there appeared in the scientific journals several claims concerning magnetochemical effects, and an equivalent number of denials of those claims. Towards the end of the 19th century Gustav Wiedemann devoted just a few paragraphs of his treatise on electricity to the description of old works and denied the phenomenon. In the same way, Wilhelm Ostwald dismissed the old claims and classified Ritter's work as "galvanic fantasies."[68]

Most physicists and chemists had forgotten this subject towards the end of the 19th century. In the decades of 1880 and 1890, however, the study of this subject received a new impetus from both the experimental and the theoretical points of view. Indeed, in the two last decades of the 19th century some magnetochemical phenomena became well-behaved and were accepted by the scientific community.

In 1881, Ira Remsen found out that a magnetic field might weaken the chemical reaction between an iron plate and a solution of copper sulfate. A few years later Paul Janet and Pierre Duhem discussed the thermodynamic interpretation of the phenomenon. As the result of theoretical analysis, it was established that there should be an electromotive force between two equal iron electrodes, if one of them is magnetised and the other is not. Therefore, in a sense, it should be possible to produce electrolysis using a magnet. Afterwards there were several attempts to detect this effect. However, the predicted electromotive force was small and experiments produced conflicting results.

The first researcher who obtained regular effects, compatible with thermodynamic predictions, was the Romanian physicist Dragomir Hurmuzescu.[69] In a long series of works, published from 1894 onward, he developed a successful experimental method that was reproduced by other authors, such as René Paillot. Hurmuzescu's work was regarded as so momentous that he was invited to report his researches at the 1900 *Congrès International de Physique*, in Paris. After Hurmuzescu's work, most authors agreed that the effect existed. However,

[65] Antoine César Becquerel, *Traité expérimental de l'électricité et du magnétisme et de leur rapports avec les phénomènes naturels*, 7 vols., (Paris: Firmin Didot, 1834–1840), at vol. 1, pp. 380–386.

[66] [Anonymous], "On the influence of magnetism on chemical action," *Encyclopedia Britannica*, 8th ed. (Edinburgh: Adam & Charles Black, 1857), vol. 14, pp. 41–42.

[67] Leopold Gmelin, *Handbook of chemistry*, translated by Henry Watts, 18 vols. (London: Cavendish Society, 1848–1872), vol. 1, p. 514.

[68] Gustav Wiedemann, *Die Lehre von der Elektricität* (Braunschweig: Friedrich Vieweg und Sohn, 1882–1883), vol. 3, §1125, pp. 967–968; Wilhelm Ostwald, *Elektrochemie. Ihre Geschichte und Lehre* (Leipzig: Von Veit, 1896), pp. 216–217.

[69] Roberto de Andrade Martins, "The rise of magnetochemistry, from Ritter to Hurmuzescu" [forthcoming].

as the effect was weak and difficult to detect, its practical importance was negligible. The subject was gradually forgotten by chemists and physicist,[70] and never attracted the attention of historians.[71]

8. ØRSTED'S OPINION

In 1830, in the article on thermoelectricity he wrote for the *Edinburgh Encyclopaedia*, Ørsted described approvingly Maschmann's and Hansteen's findings and acknowledged that they could be regarded as forerunners of the discovery of electromagnetism, because of their magnetochemical experiments:

> Two or three years before the discovery of electromagnetism, Professor Maschmann at Chrisiania, in Norway, observed that the silver tree, formed in a solution of nitrate of silver, when put in contact with mercury, (the *arbour Dianæ*) takes a direction towards the north; and the celebrated Professor Hansteen found that this direction can likewise be determined by a great magnet. As the metallic precipitation is also of galvanical nature, this observation may be considered as one of the precursors of electromagnetism.[72]

In the same article, on the other hand, Ørsted denied Ritter's early results:

> Joh. Will. Ritter, already mentioned, pursued a great number of researches upon the analogy of magnetism and electricity. He had in the year 1801 made a series of very delicate experiments upon the galvanical difference between the two magnetical poles of a steel needle. The result deduced from his experiments was, that the southern extremity of the needle was more oxidable than the northern, and that the galvanical effect of two magnetical needles upon a frog was such, that the south pole acted as the more oxidable, the north pole as the less oxidable metal. It is now acknowledged, that he has been led into error by the difference which a small disparity in the polish of the metal can produce, and which he employed insufficient means to avoid. […] The precipitation with which Ritter published these and some other erroneous statements, has thrown a shade over the name of this unhappy but ingenious philosopher, who has enriched science with several discoveries of great importance, and whose profound yet obscure ideas in many cases have anticipated the discoveries of future times.[73]

It is difficult to ascertain when Ørsted came to reject Ritter's results. In 1812, in his *Ansicht der chemischen Naturgesetze*, Ørsted still accepted that the magnetic South pole suffers a stronger oxidation.[74] He was aware that Ritter's experiments had been criticised, but he accepted their main result: the establishment of a relation between electricity and magnetism.

[70] One can still find a description of this subject in Bhatnagar and Mathur's textbook, *Physical principles and applications of magnetochemistry* (1935), but Selwood's *Magnetochemistry* (1943) does not describe this phenomenon. Shanti Swarupa Bhatnagar and K. N. Mathur, *Physical principles and applications of magnetochemistry* (London: MacMillan, 1935); Pierce Wilson Selwood, *Magnetochemistry* (New York: Interscience, 1943).

[71] In the subject volumes of the *Isis Cumulative Bibliography* it is possible to find an empty entry for "magnetochemistry."

[72] Hans Christian Ørsted, "Thermo-electricity," in David Brewster (ed.), *The Edinburgh Encyclopaedia*, 18 vols. (Edinburgh, 1830), vol. 18, pp. 573–589, at 575.

[73] Ibid p. 574.

[74] Ørsted, *Ansicht der chemischen Naturgesetze durch die neueren Entdeckungen gewonnen,* in Hans Christian Ørsted, *Scientific papers*, edited by Kirstine Meyer (Copenhagen: Andr. Fred. Høst & Søn, 1920), vol. 2, pp. 35–169, at 148.

> The remaining similarities between magnetism and electricity are so great that we need only remove the apparent contradictions in order to accept the identity of the forces in them. […] Ritter has also found that magnetized iron wire is less oxidizable at its northern end and more oxidizable at its southern end than iron, but iron or soft steel must be used here because harder steel produces less activity and, in fact, in the reversed order due to its poorer conduction and its corresponding smaller quantity of force. Under similar conditions, muscular contractions are also induced in a prepared frog if two opposite poles of a magnetized iron wire are connected to it in such a way that a closed circuit can be formed. The wires must be magnetized by means of relatively strong magnets. These experiments are still somewhat disputed by physicists, but so many have been successful that it is not easy to assume a false conclusion. […] Therefore, all the functions which can be demonstrated in electricity can also be observed in magnetism: attractions and repulsions, chemical difference, effects on the living animal body, the production of light.[75]

It is likely that Ritter's magnetochemical experiments influenced Ørsted's acceptance of the "identity" between electricity and magnetism, and hence had some bearing on his discovery of electromagnetism.

II. THE PHILOSOPHICAL BACKGROUND

After this brief historical description, one might be tempted to interpret this confusing episode as the result of mere empirical exploration, misguided by vague analogies between electricity and magnetism. The second part of this paper will attempt to reveal that a deep commitment to *Naturphilosophie* guided Ritter's researches on magnetochemistry.

At the time when he developed his magnetochemical studies, Ritter was carrying out a search for relations between the polarities of different types of "forces." This search was grounded upon a belief in the deep unity of all natural forces, and was strongly influenced by Schelling's *Naturphilosophie*. It will be also shown that Ørsted had similar beliefs, at that time.

9. RITTER ON THE PHYSIOLOGICAL EFFECTS OF GALVANISM

Around 1800, Ritter was studying several different phenomena, paying special attention to their *polarity*—that is, the existence of opposite extremes in each of them. Volta's pile provided a new impetus to his research, and he began to compare the positive/negative polarity of the galvanic poles to other oppositions—both in phenomena produced by galvanism and in other fields.

Armin Herman has provided an illuminating description of Ritter's discovery of ultraviolet light.[76] He emphasised that Ritter's guiding principle was the search for complementary or opposite aspects in light. He had heard about

[75] Ørsted, "View of the chemical laws of nature obtained through recent discoveries," (1812), in *Selected scientific works…*, p. 379.

[76] Armin Hermann, "Unity and metamorphosis of forces (1800–1850): Schelling, Ørsted, and Faraday," in Manuel Doncel, Armin Hermann, Louis Michel, and Abraham Pais (eds.), *Symmetries in Physics (1600–1980)* (Barcelona: Universitat Autònoma de Barcelona, 1987), pp. 51–62, at 58. Regarding ultraviolet light, I will use anachronistic terms here, for the sake of conciseness.

William Herschel's discovery of the infrared and knew that this radiation could be detected with a thermometer, because it produced heat. He expected to find another invisible radiation, at the other end of the spectrum, that would produce cold, but no such effect was observed. He was then led to search for another property of the hypothetical radiation, and he was successful to observe that it could produce the chemical reduction of silver chloride. His final interpretation was that the fundamental property of the infrared rays was not the production of heat, but an oxidation effect, opposite to the reduction effect produced by ultraviolet rays.[77]

In a paper published in 1803 presenting "A review of the latest advances in physics", Ørsted strongly emphasised Ritter's recent findings and depicted the establishment of the polarity of light as the most important aspect of the event we call "the discovery of ultraviolet radiation":

> Violet light is the most deoxidizing among the light rays, which Scheele's experiments have taught us. Herschel demonstrated to us that red light is accompanied by the greatest warming, and at the same time he proved that next to the red light there are invisible rays which possess an even greater warming ability. However, these discoveries were still quite isolated, without any connection to the remaining phenomena until Ritter discovered that there are invisible rays on both sides of the spectrum; that those on the violet side cause deoxidation, those on the red oxidation, and that the rays promote oxidation more, the closer they are to the red; similarly, they promote deoxidation more, the closer they are to the violet.[78]

Let us consider another example: Ritter's researches of the effect of the voltaic poles upon the sense organs.

During his early studies of galvanic phenomena, in 1792, Volta had reported that a metallic couple applied to the tip and the middle of the tongue produced an acid taste, and that the same metallic couple applied to the eye would produce visual effects.[79]

John Robinson also reported, in 1793, that a couple of zinc and silver, applied to the eye, produced a luminous flash. Stimulated by Robinson's results, Richard Fowler studied the effects produced by metallic pairs upon the several sensorial organs. He noticed that they could produce strong effects upon the ear.[80] No smell was produced, however, when the galvanic arc was applied to the nose. Humboldt and other researchers confirmed this result.[81]

[77] Besides noticing that the invisible radiation close to the violet end of the spectrum produced the reduction of silver nitrate, Ritter observed that a sample with slightly reduced silver nitrate would recover its white colour when it was submitted to red light, or to infrared radiation. Ørsted, *Expériences avec la pile électrique*…, pp. 409–410. So, he concluded that the solar spectrum is followed by invisible rays that produces oxygenation on the red side, and reduction on the violet side.

[78] Ørsted, "A review of the latest advances in physics," (1803), in *Selected scientific works*…, p. 107.

[79] Marcello Pera, *The Ambiguous Frog*: *the Galvani-Volta controversy on animal electricity*, translated by J. Mandelbaum (Princeton, NJ: Princeton University Press, 1992), pp. 107, 109. Pera observes (p. 182) that this phenomenon had already been described in 1767—many years *before* the discovery of Galvanism—by Johann Georg Sulzer.

[80] L. S. Jacyna, "Galvanic influences: themes in the early history of British animal electricity," in Marco Bresadola and Giuliano Pancaldi (eds.), *Luigi Galvani International Workshop. Proceedings* (Bologna: Universita de Bologna, 1999), pp. 167–185, at 167, 171–172.

[81] Paul Fleury Mottelay, *Bibliographical History of Electricity and Magnetism* (London: Charles Griffin, 1922), pp. 307, 311, 333.

The invention of Alessandro Volta's new apparatus (the pile) was communicated in a letter to Joseph Banks. There he described several physiological effects produced with his instrument. These included shocks, the pain produced by the voltaic current upon wounds, the acid or bitter taste produced on the tongue, and luminous sensations on the eye. When he applied to his ear the wires connected to the pile, he felt a very strong shock and some indefinite noise.[82] No specific sensation was produced on the nose. The effects were stronger but altogether similar to those produced by the galvanic arc.

Most researchers, after confirming Volta's experiments, did not pursue those physiological investigations. Ritter, however, was not content with those results. He applied metallic wires attached to the voltaic pile to his eyes, skin, nose, etc. and described the observed effects. His results were published in 1801. They were much more definite than those of the former authors. Instead of describing just a flash of light when he applied the pile to his eye, his account was full of details. When the zinc pole (positive lead) of the battery was linked to his eye, Ritter observed first a flash and then a blue colour. If the contact was kept for some time, he observed that the objects he looked at seemed smaller and less distinct. When contact was broken he saw again a flash and then a red colour. Opposite effects were described when he connected his eye to the silver or copper pole of the pile (negative lead). After the initial flash he saw a red colour, and the objects he looked at seemed larger and more distinct. After contact was broken, he saw a blue colour.[83]

In the case of the other sense organs Ritter also arrived at new results. The following table summarises Ritter's conclusions about the physiological effects of the two different kinds of voltaic electricity:

Positive pole	Negative pole
1. expansion of the tissues;	1. contraction of the tissues;
2. sensation of heat;	2. sensation of cold;
3. stronger pulsation;	3. weaker pulsation;
4. the eyes see a red colour, larger and more distinct images;	4. the eyes see a blue (or violet) colour, smaller and less distinct images;
5. the tongue perceives an acid taste;	5. the tongue perceives an alkaline taste;
6. the nose has a reduced sense of smell, as that produced by acids;	6. the nose gets the impression of an ammoniacal smell;
7. the ears sense a grave sound.	7. the ears sense an acute sound.

Of all those distinctions, only the acid and bitter tastes had been described by previous authors. The new effects reported by Ritter were not confirmed by later researchers.

[82] Alessandro Volta, "On the electricity excited by the mere contact of conducting substances of different kinds," *Philosophical Transactions of the Royal Society* 90 (1800), pp. 403–431, at 420–427.

[83] Johann Wilhelm Ritter, *Versuche und Bemerkungen ueber den Galvanismus der Voltaischen Batterie, Annalen der Physik* 7 (1801), pp. 431–484, at 474–475.

10. ØRSTED MEETS RITTER

Ørsted first met Ritter when the later was publishing those results. It is well known that in the summer of 1801 Ørsted began a series of travels in Europe. He first visited Germany, where he met Fichte and Schlegel (in Berlin) and later Schelling and Ritter in Jena. After spending several months in Germany he travelled to France and to the Netherlands and returned to Copenhagen in the end of 1803.

Ørsted was deeply interested in galvanism—as many other people at that time—and, having heard about Ritter's researchers, obtained a letter of introduction and met him on the 18th of September. In the following days Ritter showed him many new experiments, and Ørsted was immediately influenced by him. He was soon convinced that Ritter's work was of the highest importance. A few months later, Ørsted travelled to France, where he began to publicise Ritter's work. Ritter's experiments and ideas will be hereafter presented, whenever possible, through Ørsted's reports.[84] The relevance of this kind of source as providing an elucidation of Ørsted's ideas will be discussed later.

Ørsted communicated some of Ritter's experiments to the *Société Philomatique*, and obtained a positive reaction. He then wrote to Ritter and asked him to communicate any new discoveries he made, and he was "very flattered" for receiving a series of letters with detailed descriptions of his experiments. Ritter authorised him to announce all his new discoveries to the French physicists.[85] From his writings about Ritter's researches it is possible to perceive that Ørsted espoused his ideas and did not doubt his experimental findings.

Ørsted claimed that all previous researchers had given little attention to the effects of electricity upon the organs of sensation. Ritter, however, studied those effects with great care, "even at the price of risking his own health."[86]

> Mr. Ritter reduced all the effects of the pile on the animal body to expansions and contractions. The positive pole increases the volume of several parts of the human body; and the negative one produces a diminution of the same parts. When the tongue is put into contact with the positive lead, and the negative one is applied to any other part of the body, and they are left in such a position for some minutes, there arises a small boil on the tongue. When the negative lead is put in contact with this organ, it likewise produces a small depression. When the wet hands are put in contact with the poles of the pile for some minutes, the pulse of the hand in contact with the positive pole becomes sensibly stronger, and that of the hand touching the negative one becomes weaker. […] Expansion is followed by a sensation of heat, and contraction by a sensation of cold.

[84] Kirstine Meyer, "The Scientific life and works of H.C. Ørsted," in Meyer (ed.), *H.C. Ørsted, Scientific Papers….*, pp. xxiii–xxiv; Dan Ch. Christiansen, "The Ørsted-Ritter partnership and the birth of Romantic natural philosophy," *Annals of Science* 52 (1995), pp. 153–185.

[85] Hans Christian Ørsted, *Expériences sur un appareil à charger d'électricité par la colonne éléctrique de Volta; par M. Ritter, à Jena. Présentées à l'Institut National par J. C. Ørsted, docteur à l'Université de Copenhagen, Journal de Physique, de Chimie, d'Histoire Naturelle et des Arts* 57 (1803), pp. 345–368, at 368.

[86] Hans Christian Ørsted, *Expériences avec la pile électrique…*, p. 404.

> The action of the pile on the organs of the senses is modified by the particular nature of each of them; it is remarkable that the two poles of the pile produce in some way the two extremes of each type of sensation.[87]

Perhaps Ørsted had not been able to reproduce all those effects—or, maybe, he heard that other people did not confirm them—and added this remark:

> Those experiments require a lot of care. To repeat them successfully it is necessary to be acquainted with the exhaustive descriptions that the author has provided in several highly detailed treatises.[88]

Later publications by Ørsted allow us to conclude that in the following years he maintained his acceptance of Ritter's results, and deemed them of the utmost importance. In 1807, in a review of the most relevant recent advances of chemistry (in his opinion), Ørsted called the attention of his readers to Ritter's experiments:

> […] electricity, especially in the form in which it appears in galvanism, is capable of producing the extremes of all sensations; in the gustatory organ acidity and alkalinity, in the olfactory organ a similar contrast, in the eye the two extreme prismatic colours, in the ear higher and deeper tones, in the tactile sense change in temperature and expansion and contraction, in the nerves changed incitability.[89]

11. RITTER'S SEARCH FOR THE RELATION BETWEEN POLARITIES

Both Ritter's discovery of ultraviolet radiation and his studies of the physiological effects of galvanism show his experimental involvement with the study of polarities. Was this a mere empirical search, or was it guided by some theoretical ideas? Anja Jacobsen has already emphasised that Ritter was attempting to demonstrate, by experiment, his belief about the fundamental principle of polarity in different areas of natural philosophy.[90] At the time (1801) when he discovered the invisible "chemical rays" (ultraviolet rays), Ritter announced his research programme in the following words:

> It will be the result of a larger factual investigation to exhibit the polarity of chemistry, electricity, galvanism, magnetism, heat, etc., in accordance with their principles as one and the same in all.[91]

Notice two fundamental ideas that clearly appear here: the *polarity* of all forces and their *unity*. We can compare Ritter's words with Schelling's: "[…] it is the first principle of a philosophical doctrine of nature to *go in search of polarity and dualism throughout nature*."[92] (Whether Ritter got this idea from Schelling or not

[87] Ibid 404–405. A shorter version of this account can be found in: Ørsted, "Experiments with the electric pile, by Mr. Ritter, of Jena," *Journal of Natural Philosophy, Chemistry, and the Arts*, 8 (1804), pp. 176–180.

[88] Ibid p. 405.

[89] Ørsted, "Reflections on the history of chemistry," (1807), in *Selected Scientific Works…*, p. 252.

[90] Anja Skaar Jacobsen, *Between Naturphilosophie and tradition: Hans Christian Ørsted's dynamical chemistry* (Unpublished Ph.D. thesis, University of Aarhus, 2000), p. 70.

[91] Ritter, apud ibid. p. 60.

[92] Schelling, *On the world soul*, *apud* Schelling, *Ideas for a* philosophy *of nature*, translated By Errol E. Harris and Peter Heath (Cambridge: Cambridge University Press, 1995), p. ix.

will be discussed later. Whatever the origin of his ideas, it is clear that Ritter's main concepts were polarity and the unity of all forces in nature. All phenomena were produced by two opposite forces, actions or qualities, tending to equilibrium. Every force in nature was limited by an opposing force. And Ritter conceived heat, light, electricity, galvanism, and magnetism as different forms of the fundamental forces of attraction and repulsion.[93]

> Johann Wilhelm Ritter (1775–1810) may well have concluded on the basis of Galvani's discoveries that the same forces which generate electricity also produce chemical effects, but Volta's final discovery threw far more light on this truth. Ritter used this with rare spirit and power to show how the same natural forces manifest themselves in chemical, electrical, and magnetic effects, in light, in heat, indeed, even in the manifestations of life in organic bodies.[94]

In later works, Ørsted regarded the identity of electricity, galvanism, chemical forces, magnetism and the "space-filling forces" as the basic idea of the new chemistry, and presented a list of the forerunners of this idea: Priestley, Wilke, Kratzenstein, Herny, Karsten, Forster, Gren, Lichtenberg, Hube.[95] According to him, however, none of them had attained the central discovery:

> However, as these otherwise outstanding men, misled in part by the assumption of a characteristic electrical substance, regarded the particular mode of action which we call electricity as the basis for all other phenomena, instead of assuming it to be one of the various realizations of the universal natural forces, they limited their horizon and gave the entire grand theory, which should have originated from this, the appearance of a narrow hypothesis. On the other hand, it must be admitted that it was scarcely possible to develop this view more completely before our knowledge of electricity and several related effects had progressed to greater maturity so that this advance was naturally reserved for more recent times. **Ritter can therefore be regarded as the creator of modern chemistry**. His comprehensive ideas and his achievements, undertaken with such great vigour and exertion, spread a great light in all directions. To a certain extent, Winter [*sic*] deserves to be placed next to him.[96]

It is essential to distinguish Ritter's ideas from our current views on energy conservation and the possibility of transformation of the different "forces" in one another. Ritter was not attempting to find a quantitative relation between the amount of different forces that could be mutually transformed. He accepted that natural phenomena are produced by a pair of opposite fundamental forces, and that those contrary powers will become manifest as different polarities in diverse conditions. Since all polarities have a common source, they must exhibit specific, non-arbitrary connections.

In a paper published in 1803 presenting "A review of the latest advances in physics," Ørsted referred to the associations that had been found by Ritter and attempted to provide a rationale for some of them:

> This student of nature [Ritter] has also brought us enlightenment concerning the other senses, but so far it has yielded less conspicuously satisfying results. The fact

[93] Jacobsen, *Between Naturphilosophie and tradition…*, pp. 60–76.

[94] Ørsted, "First introduction to general physics," (1811), in *Selected scientific works…*, p. 304.

[95] Ørsted, "View of the chemical laws of nature obtained through recent discoveries," (1812), in *Selected scientific works…*, p. 312.

[96] Ibid. pp. 312–313; my emphasis.

> that the *positive* pole leaves an *acid*, the *negative* an *alkaline* taste on the tongue had previously been noticed, but that the positively galvanized ear perceives sounds as *softer*, the *negatively* galvanized as louder, is a discovery of the same nature. The negative pole evokes an ammoniac smell, the positive seems to deaden the smell. As far as *touch* is concerned, galvanism has a *hot* and a *cold* pole, about which we may soon expect more detailed enlightenment.
>
> If we now take a look at previously known facts from this vantage, we see once more a great many phenomena converging towards a focal point. The positive pole generates oxygen gas from water, and this transforms combustible substances into acids or acid-like substances; the negative generates hydrogen gas, and this is a primary component of the few alkalis which we have so far been able to decompose. This yields enlightenment about the effect of galvanism on both taste and smell, but in the latter regard, we need to note that oxidizing substances (like *gas muriatique oxygéné*) also suppress smell and cause catharrs. As far as hearing is concerned, we recall that, according to Chladny's [*sic*] discovery, the notes of a flute sound far higher in hydrogen gas than in oxygen gas.[97]

Notice that, for Ørsted, the relations between the poles of the pile and the specific sensations they produce are not arbitrary, but should be understandable in a broader framework.

Above all physiological effects of galvanism, Ørsted emphasised the relation between the positive pole and expansion, and between the negative pole and contraction:

> However, it will forever remain a major discovery concerning the effect of galvanism that the *positive pole causes expansion, the negative contraction*. This law, in its nature so simple, in its application so fruitful, already explains why the eye sees everything larger in the positive state and everything smaller in the negative. At this moment, it would be too daring to establish all the important conclusions which can be drawn from this discovery. Instead, we want to recall only two secondary discoveries by the same student of nature [Ritter] which give cause for much thought. If the tongue is positively galvanized (of course continuously), a swelling appears at the affected spot, whereas a depression is produced by the negative pole. Positive galvanism makes the pulse big, negative makes it small. (Here, fast and slow should not be confused with big and small.).[98]

Let us recall that in his first communication of Ritter's physiological researches he had already pointed out this important feature: "Mr. Ritter reduced all the effects of the pile on the animal body to expansions and contractions."[99]

12. THE TWO FUNDAMENTAL FORCES OF NATURE

According to Schelling's *Naturphilosophie*, the productive nature has two opposite activities: repulsion and attraction, which provide the basis for all polarities in nature. Phenomena can take place only when there are oppositions. All natural effects are the products of two opposing powers: "[…] Nature is able to achieve the entire manifold of her phenomena, on the small scale as well as on the large, by means of opposing forces of attraction and repulsion." Positive force is a repulsing,

[97] Ørsted, "A review of the latest advances in physics," (1803), in *Selected scientific works…*, p. 108.
[98] Ibid. p. 108.
[99] Ørsted, *Expériences sur la pile électrique…*, p. 404.

expansive, elastic or repelling force. Negative force is restrictive, attractive.[100] The interplay of those opposite forces produces all natural phenomena:

> In order to maintain this perpetual exchange, Nature had everywhere to count upon *contradictories*, had to set up *extremes*, within which alone the endless multiplicity of her phenomena was possible.[101]

The same idea appears in Ritter's works:

> Proof for the absolute polarity in nature. Nature is activity [*Handeln*], and it is nature only to that extent. Activity requires however a diversity, because only by this does activity arise[…].Each action thus presupposes difference. This however is contrast, polarity. And nature only is, where activity is, therefore polarity must be everywhere.[102]

The conflict and mutual replacement between opposite forces was regarded as the source of all phenomena. The opposite electrical charges, the two magnetic poles, the contrast between acids and bases and many other dualities were regarded by the Romantic philosophers as examples of this basic polarity of nature.

According to Schelling, matter can be reduced to the fundamental forces: "Matter and bodies, therefore, are themselves nothing but products of opposing forces, or rather, are themselves nothing else but these forces."[103] This entails a fundamental unity of all kinds of matter: "All matter is intrinsically one, by nature pure identity; all difference comes solely from the form and is therefore merely ideal and quantitative"[104]; "[…]everything we call matter is simply a modification of one and the same matter, which admittedly, in its absolute state of equilibrium, we do not know by sense, and which must enter into special relationships to be knowable for us in this way."[105] In the same way as there is only one single basic matter, according to Schelling there is one single pair of opposite forces that can display different forms. Schelling attempted to identify positive and negative electricity respectively with the fundamental repulsive and attractive forces by taking into account their general properties:

> We can accordingly state the general law of the electrical relation of bodies thus: *That one of the two* [bodies] *which enhances its cohesion in opposition to the other will have to appear as negatively electric, and that one which diminishes its cohesion, positively electric*.[106]

Instead of multiplying forces to explain the variety of natural phenomena, Schelling searched for a hidden unity:

> But our mind strives towards *unity* in the system of its knowledge. It does not tolerate a special principle being thrust upon it for every single phenomenon, and it believes that it sees *Nature* only where it discovers the greatest simplicity of laws amid the greatest variety of phenomena, and the most stringent parsimony of means in the highest prodigality of effects.[107]

[100] Schelling, *Ideas for a philosophy of nature…*, pp. 135, 187.
[101] Ibid. p. 87.
[102] Johann Wilhelm Ritter, *Fragmente aus dem Nachlass eines jungen Physikers* (Leipzig: Infel, Verlag, 1938), p. 31.
[103] Schelling, *Ideas for a philosophy of nature…*, p. 156.
[104] Ibid. p. 137.
[105] Ibid. p. 223.
[106] Ibid. p. 118.
[107] Ibid. p. 111.

The interplay of the two basic forces produce all qualitative changes in matter, and for that reason Schelling regarded their study as the foundation of chemistry: "The subject-matter of chemistry is attractions and repulsions, combinations and separations, insofar as they depend upon qualitative properties of matter."[108] The same attractive and repulsive forces that are the basis of electricity are also the causes of chemical affinity: *That which makes substances negatively electric is at the same time that which makes them combustible*, or, in other words: *Of two substances, that which has the greatest affinity for oxygen always becomes negatively electrified.*[109]

We can find similar ideas in Ørsted's writings:

> […]all chemical effects can be traced back to the manifestation of two principal forces, widespread throughout nature, whose properties in their free state, however, cannot easily be found by chemical means. From another side, however, we have arrived at greater knowledge of these forces. In electric, galvanic, and magnetic effects two opposite forces have been found, widespread throughout nature, and it has been possible to investigate the laws which govern their freest manifestations and pursue them through the most diverse conditions to the point where they also produce chemical effects.[110]

> The dynamic theory […] extends the scope of chemistry far beyond its old bounds. Electricity, magnetism, and galvanism now become part of chemistry, and it is shown that the very same fundamental forces which generate these effects also produce the chemical ones in another form.[111]

One usually ascribes the origin of this dynamical view of nature to Immanuel Kant.[112] In some sense this is true, since Kant reduced the basic properties of matter to attractive and repulsive forces. However, Kant did not attempt to include in his dynamical view the different forces that concerned the Romantic philosophers: light, heat, electricity, magnetism, galvanism, and chemical forces. It was Friedrich Schelling who took this step.

Kant's opposite forces had a simple function: to account for the structure of matter (and, perhaps, its density). Schelling's polarity, on the other hand, accounted for several phenomena such as magnetism, electricity, and chemical forces, being therefore widely different from Kant's attraction and repulsion.[113] According to Robert Stern, it was Fichte (not Kant) who was the main influence acting upon Schelling's views on the basic forces of matter.[114]

Nowadays, as Kant is a more honorable ancestor than Schelling, several authors attempt to detach the Romantic nature philosophy from Schelling and connect it exclusively with Kant. That seems to me a mistake, however.

[108] Ibid. p. 206.

[109] Schelling, p. 102.

[110] Ørsted, "First introduction to general physics," (1811), in *Selected scientific works…*, p. 291.

[111] Ørsted, "Reflections on the history of chemistry," (1807), in *Selected scientific works…*, p. 252.

[112] Timothy Shanahan, "Kant, *Naturphilosophie*, and Ørsted's discovery of electromagnetism: a reassessment," *Studies in the History and Philosophy of Science* 20 (1989), pp. 287–305; Kaiser, "Symmetries in Romantic physics…, p. 78.

[113] Jacobsen, *Between Naturphilosophie and Tradition…*, pp. 84–85.

[114] Stern, in Schelling, Ideas for a philosophy of nature…, pp. xvi–xx.

There are, of course, both similarities and differences between Ritter's and Schelling's ideas about the unity and polarity of forces. Although there are differences between their views,[115] Ritter always retained the ideas of a unity of the forces of nature, the relation between electricity, chemistry, and other forces, and the principle of polarity, going as far as stating that "there must be polarity everywhere."[116]

If one believes that all forces of nature are different forms of a single primary force (*Urkraft*), he / she will expect to find a deep relation between the poles (or extremes) of the several types of force. Schelling provided several examples taken from the recent scientific findings—especially in chemistry and galvanism—but did not pursue empirical investigations. He believed that speculation was a safe method.[117] Ritter did not agree. He added a strongly experimental approach to Schelling's speculations, and pursued empirical inquiries. Polarity and the unity of forces were the guiding ideas of his researches, but he felt the need to manipulate nature and to observe the results. So, the concept of polarity did not represent for Ritter just a philosophical framework, but also a heuristic principle, directing him to find new phenomena.[118] Schelling's theoretical influence upon Ritter can be noticed in his presentation of the natural phenomena in pairs of polar opposites. On the other hand, Ritter's experimental findings influenced Schelling.[119]

13. THE EMBLEMATIC WAY OF THINKING

It is important to stress that Schelling's approach was not just a different philosophical system, but a different way of thinking about nature. To exhibit this difference as clearly as possible, I will choose an indirect route, including a short visit to China in order to elucidate the emblematic way of thinking. The meaning of "emblematic" I would like to apply is not unlike Ashworth's use of this term, as applied to Renaissance thought.

> The emblematic world view is, in my opinion, the single most important factor in determining late Renaissance attitudes towards the natural world, and the contents of their treatises about it. The essence of this view is the belief that every kind of thing in the cosmos has myriad hidden meanings and that knowledge consists of an attempt to comprehend as many of these as possible. To know the peacock, as Gesner wanted to know it, one must know not only what the peacock looks like but what its name means, in every language; what kind of proverbial associations it has; what it symbolizes to both pagans and Christians; what other animals it has sympathies or affinities with; and any other possible connection it might have with stars, plants, minerals, numbers, coins, or whatever.[120]

[115] Ritter, Goethe and Novalis criticized Schelling's speculations, but they adhered to the idea of polarity. See Kaiser, "Symmetries in Romantic physics…," p. 80.

[116] Hermann, "Unity and metamorphosis of forces…," p. 58.

[117] After the discovery of electromagnetism and electromagnetic induction, Schelling claimed that the relations between chemistry, magnetism and electricity had been anticipated by German philosophers—including himself, of course. See Hermann, "Unity and metamorphosis of forces…, p. 60.

[118] Kaiser, "Symmetries in Romantic physics…, p. 81.

[119] Jacobsen, *Between Naturphilosophie and tradition*…, pp. 66–67.

[120] William B. Ashworth, Jr., "Natural history and the emblematic world view," in David C. Lindberg and Robert S. Westman (eds.), *Reappraisals of the Scientific Revolution* (Cambridge: Cambridge University Press, 1990), pp. 303–332, at 312.

When Marcel Granet attempted to describe ancient Chinese thought to 20th-century occidental readers, he stressed that the Chinese words did not correspond to *concepts*. They were not mere *signs*, but should be understood as *emblems*.[121] Instead of corresponding to general and abstract ideas, the words evoke "an indefinite complex of particular images." A particular emblem may encompass what we would describe as incompatible concepts related to space, time, colour, etc. The same emblem, for instance, characterises the era and empire of the Tchou dynasty, the red colour, the summer season, the South region. The East region is related to benevolence, flexibility, to muscles, to the liver, to the spring season and to green colour.[122] According to Granet, the emblematic character of the Chinese words establishes a series of relations that would be meaningless if one attempted to understand them as conceptual links:

> Mountains and humpback people are abundant to the West and they characterise it, in the same way as the heaps of the harvest that evoke Autumn. A hump is a skin excrescence; the skin depends on the lungs, lungs depend on the Autumn and are related to the white colour. But when we refer to skin we refer to leather and armour, that is, war and punishment. So, the western barbarians are regarded as endowed with a warlike humour, and executions—both military and penal ones—are reserved to the Autumn, and the Spirit of Punishment, who is remarkable by his white hair, lives in the West. Hair comes from the skin, and white is the meaningful emblem of West and Autumn, and also of the Yin age. That era was inaugurated and characterised by the kingdom of T'ang the Victorious, a hero who became famous for the punishments he inflicted and because of his habit of walking with his body completely bent.[123]

This way of thinking is alien to contemporary scientific thought, but it is not far from the way of thinking introduced by Schelling and used by Ritter and Ørsted in some of their researches.

There are other similarities that can be found between the ancient Chinese thought and Schelling's fundamental polarities. In one of the chapters of his book Granet discusses the meaning of the couple of words *yin* and *yang*. Some interpreters of the Chinese thought construe *yin* and *yang* as two *forces*. Other scholars interpret them as *substances*. However, those are occidental conceptual categories that do not apply in a strict form to the Chinese thought.[124] *Yin* and *yang* might be regarded both as forces and substances, and also as corresponding to other categories; however, they can also be regarded as neither forces nor substances. They are general opposite and complementary conditions that follow each other.

According to Granet, in an ancient book, the *Shi Jing*, the word *yin* evokes the idea of cold and cloudy weather, or rainy sky. It is applied to the inner part of things, to dark and cold places where, during the summer, it is possible to preserve ice. Any shadowy place, such as the north side of a mountain or the south side of a river, is also described as *yin*. The word *yang*, on the other hand, is associated to heat and to the Sun. It may be used to describe the male attitude

[121] Marcel Granet, *La Pensée Chinoise* (Paris: La Renassance du Livre, 1934), pp. 37–39
[122] Ibid. p. 87.
[123] Ibid.
[124] Ibid. pp. 115–116.

of a dancer in action. It applies to spring time, when the heat of the Sun begins to produce its effects and to the tenth month of the year, when winter begins its retreat. This is the month when buildings should begin to be erected. Sunny and bright places, such as the south side of a mountain and the north side of a river, are also described as *yang*.[125]

There are many other meanings associated to those words. The following table presents some of them:

Yin	Yang
female	male
cold	hot
a closed door	an open door
something hidden	something manifest
the act of entering	the act of coming out
inside	outside
darkness	brightness
acute sounds	grave sounds
light weight	heavy weight
rain	dew
night	day
winter	summer
earth	sky
moon	sun
water	fire
even numbers	odd numbers

One can perceive a similarity between this Chinese way of comparing widely different things, and Ritter's association between colours, sounds, temperatures, tastes, etc. Of course, I am not claiming that there was an influence of the old emblematic Chinese thought on Ritter's ideas, but it is impossible to deny a similarity in the search for polarity or dualities and in the attempt to connect them in an integrated unitary view of nature.

14. THE SYMBOLIC DIMENSION OF *NATURPHILOSOPHIE*

Some authors who wrote about the German Romantic movement have already stressed the symbolic outlook of their world view: "[…] Everything is sign and symbol, […] the whole world has 'merely indicatory or physiognomic significance'. The whole world should be interpreted as a gigantic system of hieroglyphics, as the *language* of God or the *book* of nature."[126]

> The chain of natural laws which through their actions constitute the essence of every object can thus be regarded as a *thought of nature* or rather an *idea of nature*. And as all natural laws together form a unity, *the entire world is the expression of an infinite,*

[125] Ibid. pp. 117–118. [The Chinese work is known as the *Book of Songs* or *Odes*, given in Granet's French text as the *Che King*—Ed.]

[126] Alexander Gode-Von-Aesch, *Natural Science in German romanticism* (New York: AMS Press, 1966), p. 228.

> *universal Idea which must be one with an infinite Reason, alive and active in everything*. In other words, *the world is merely the revelation of the combined creative power and reason of the Godhead*.[127]

According to Alexander Gode-von-Aesch, this idea was born in the late 18th century and was developed by Ritter (and other philosophers). This way of thinking led to identify widely different but symbolically related entities: "[…] it might be shown that romantic imagery tends unconsciously to be of the identity type. When Hardenberg says, for instance, that the brain resembles the testes, he is doubtless in the midst of his magic idealism and conceives of thinking as a procreative act."[128]

The symbolic way of thinking is clearly exhibited in Schiller's, Ritter's, and Ørsted's writings:

> Finally, for the ultimate task of a physics of chemistry, which also has to depict in these phenomena the totality alone, **it is necessary to grasp their symbolic character** and connection with higher relationships, since every body of individual nature is again, in its idea anyway, a universe. Only if we seek among chemical phenomena, no longer for laws that are peculiar to them as such, but for the general harmony and regularity of the universe, will they come under the higher relationships of mathematics […].[129]

> Each point in the universe is a nature *en miniature*, but in everything the artist copied the original from another side.[130]

> The ancients worshipped the universal substance under the name of Vesta (Hestia), and this indeed is the sensible image of fire. In this they left us a hint that fire is nothing other than the pure substance breaking through in corporeality, or a third dimension […].[131]

> The most perfect process of combustion will display itself to us where the conflict of universal and particular is perfectly equalized in that attempted process of generation, where the universal and particular of relative cohesion reaches indifference, **yielding the hermaphroditic product of water**, which, as absolute liquid, is not only the total extinction of the first two dimensions in the third, but also, **through the particular is wholly Earth and through the universal wholly Sun**; and just here in this equalization the Sun breaks through most completely, except that because of the element of Earth which is included therein, it cannot show itself purely as light, but only as fire (light combined with heat).[132]

> White is the color […] which keeps the eye healthy; the light of the sun is white[…]white presents purity, innocence, love, harmony, etc. […] Also the water is white, harmony, purity, innocence, the source of everything on Earth.[133]

In his *Reflections on the History of Chemistry* (1807) Ørsted remarked that the medieval thought and modern science were widely different, but had some features in common, including the search for unity:

[127] Ørsted, "First introduction to general physics," (1811), in *Selected scientific works*…, p. 252.
[128] Gode-Von-Aesch, *Natural Science in German romanticism*…, p. 219
[129] Schelling, *Ideas for a philosophy of nature*…, p. 220; my emphasis.
[130] Ritter, *Fragmente aus dem Nachlass* …, p. 57.
[131] Schelling, *Ideas for a philosophy of nature*…, p. 65.
[132] Ibid. p. 66; my emphasis.
[133] Ritter, *Fragmente aus dem Nachlass*…, p. 39.

> The mystical tendency of the Middle Ages is so opposite the striving of our time towards perfect clarity that it might easily seem impossible for them both to have a share in the truth. To deny the contrast between them would be against evident truth, but no contrast can exist where there is nothing in common.[…] Every effort towards insight into nature aims at bringing separate phenomena under a common terminology, at discovering laws which everything obeys, in short, at bringing the unity of reason to nature. The mystical age had at least this endeavour in common with ours.[134]

Ørsted understood this search for unity as symbolic. As an instance, he discussed the medieval belief in a relation between the planets and the metals: "At first glance, this seems mere fantasy, but if we consider the matter more closely, we find an underlying truth." He then presented some arguments favorable to the idea, such as this: "[…] it is worth noticing that gold, which was the sun of metals according to that time, is deposited primarily around the equator and also maintains its metallic nature most perfectly in all assays." Finally, he acknowledged that there was (yet) insufficient basis for such a comparison: "I admit that, in spite of all our greater knowledge, we are still not able to advance such a comparison between the metals and the planets, but the basic idea is hardly to be disdained."[135]

In his own work, Ørsted usually employed this symbolic method. One instance is his view of positive and negative electricity:

> The primary form of positive electricity is the radiating point, of the negative, on the other hand, the circle so that one seems to form the internal, the other the external, one the point which radiates from its centre in all directions, the other the enclosing periphery. The natural symbol of electricity, then, is a circle with its radii, the symbol of positive electricity the radiating point, and of negative electricity the point surrounded by concentric circles. These symbols undoubtedly deserve our fullest attention, for they reappear everywhere, and who knows whether all of Nature's mathematics does not lie hidden in them! (ØRSTED, On the harmony between electrical figures and organic forms, 1805, in *Selected scientific works*, p. 185)

In 1804 Ørsted described that the two galvanic poles produced different forms similar to a vegetation and its roots:

> […] I put a solution of acetate of lead in contact with the poles of the pile. The dissolved lead calx should be oxidized more strongly on the oxygen side and be precipitated as brown lead calx, but on the hydrogen side it should be reduced and thus be precipitated. This indeed happened. On the hydrogen side I obtained a beautiful metallic lead vegetation but on the oxygen side a brown lead calx formed shapes comparable to the positive soot figures. I would prefer to compare these shapes with plant roots. Could it be that oxidation and deoxidation are associated with definite forms which occur if no external causes oppose them? Could the organic forms be necessary products of the internal chemical process?[136]

In 1805 Ørsted applied this idea to the structure of trees:

> […] In the simplest, purest experiments, which actually serve as a basis for all the chemical discoveries of more recent physics, we find the process of reduction (deoxidation) united with the external form of vegetation, whereas the process of combustion is accompanied by a form whose boundary is the circumference of a circle when it radiates from a central point or parallel lines when it radiates from a central line, that is, we see in it the norm of the internal form of a plant. Therefore we should

[134] Ørsted, "Reflections on the history of chemistry," (1807), in *Selected scientific works*…, p. 247.
[135] Ibid. p. 248.
[136] Ørsted, "Galvano-chemical observations," (1804), in *Selected scientific works*, p. 168.

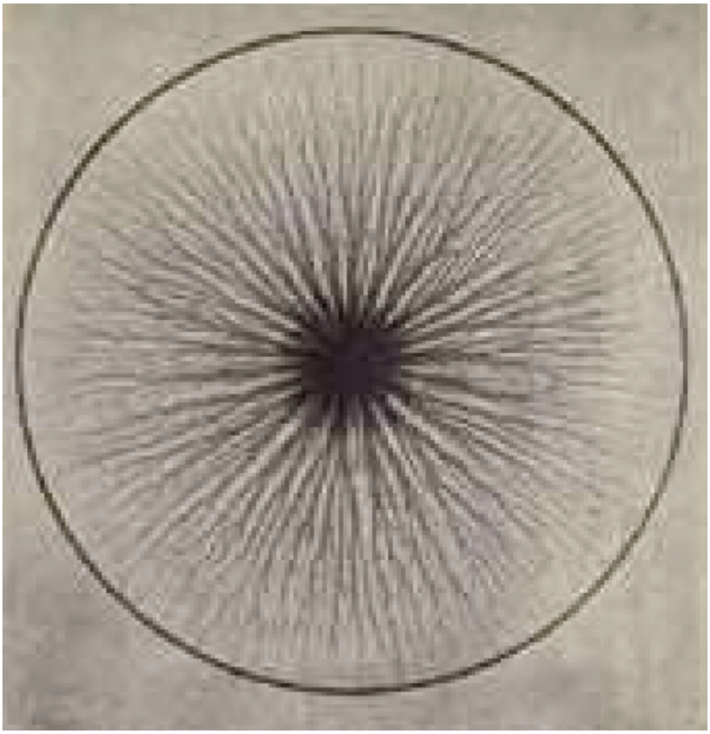

Fig. 1. According to Lichtenberg, positive electricity produces radial figures and negative electricity produces concentric circles. Ørsted joined both figures to produce "the natural symbol of electricity," that might be depicted as above.[137]

expect to find the same formations everywhere in nature, assuming that the same form must follow the same force unless the effect of foreign forces change it.

We need only glance at nature to find our assertion confirmed. The plant lives solely by the influence of sunlight, and thereby it constantly generates oxygen gas and is deoxidized or reduced. The same form and the same chemical process which were united in the electrical effect are so here, too. Internally, however, the plant must oxidize.[…]Another reason can be found in the nature of the plant juices themselves. These are acidic, and those that are not to any noticeable extent still have a tendency in this direction so that they are always acidified by fermentation. Thus we discover the same agreement between form and force in the interior of the plant as in its exterior, and in both the most perfect similarity to what we have seen in electricity. We could add that plant fibers appear as parallels only when viewed from one direction, that is, lengthwise, but when viewed crosswise, the circle is the predominant figure and forces us to acknowledge the negative in the interior of the plant, in every direction.[138]

[137] Figure reproduced from Everett Lee and C. M. Poust, "Measurement of surge voltages on transmission lines due to lightning," *General Electric Review* 30 (1927), pp. 135–145, on p. 134.

[138] Ørsted, "On the harmony between electrical figures and organic forms," (1805), in *Selected scientific works…*, p. 186.

15. RITTER'S EMBLEMATIC THOUGHT

Ritter's attention was called by opposite polarities in several phenomena (oxidation versus reduction, hydrogen versus oxygen, etc.) and he attempted to establish definite relations between dualities belonging to different realms. He knew that positive and negative galvanism produced acid and bitter tastes, and he expected that the same causes would produce opposite sensations when applied to the other sense organs. And that was exactly what he thought he had found, as described above. He found out that positive galvanism was related to the red "pole" of light, and negative galvanism to the blue "pole," and other similar associations that can be ascribed to an emblematic way of thinking.[139] The same fundamental polarity was producing different sensations, as it acted upon different organs, as suggested by Schelling:

> Light and heat are mere expressions of our feeling, not a designation of that which acts upon us. From the very fact that light and heat affect quite different senses, and work so utterly differently, we can already infer that in both cases we are designating mere modifications of our organ.[140]

One might think that, when Ritter attempted to find a definite relation between such different things as colours and electricity, he was just using some kind of analogy—as Newton's analogy between the colours of the rainbow and the musical notes. Anja Jacobsen, for instance, explained Ørsted's parallels between electricity, combustibility, and acidity–alkalinity as the use of the same model of explanation for several phenomena "by virtue of analogies."[141] Andrew Wilson has also pointed out that Schelling, Steffens, Ritter, Winterl, and Ørsted had identified "whole series of analogies between physical phenomena."[142] I will claim, however, that Ritter's (and also Ørsted's) emblematic or symbolic thought was something much stronger than a mere analogy. From a historical point of view, the concept of "analogy" was born in mathematics where it meant an equality between ratios or proportions.[143] Afterward this word came to be used in several different senses.[144] Although there is a wide range of "analogy concepts," let us assume the following statement as a reasonable account of most recent uses of this word: two objects A and B of any kind are analogous if there are parts, properties or relations that are similar or equal in both A and B (that is, if they have some equivalent features) and if, beside that, they have some difference.

[139] "It seems that Ritter's attempt is an amazing example for the notion of polarity and how far the idea of polarity could influence experimental data" See Kaiser, *Symmetries in Romantic physics*…, p. 82.

[140] Schelling, *Ideas for a philosophy of nature*…, p. 134.

[141] Jacobsen, Between *Naturphilosophie* and tradition…, p. 133.

[142] Andrew D. Wilson, "Introduction," in *Selected scientific works*…, pp. xv–xl, at xxix.

[143] Even in ancient Greek thought, analogy was also regarded as a method of suggesting explanations of natural phenomena. G. E. R. Lloyd, "Analogy in early Greek thought," in Philip P. Wiener (ed.), *Dictionary of the history of ideas: studies of selected pivotal ideas* (New York: Charles Scribner's Sons, 1973), vol. 1, pp. 60–63, at 60.

[144] Mary Hesse, "Models and analogy in science," in Paul Edwards (ed.), *The Encyclopedia of Philosophy* (New York: Macmillan & The Free Press, 1967), vol. 5, pp. 354–359.

Notice that, according to this concept, two identical objects are not analogous.

If two objects are analogous, this similarity *suggests* that they might have other equivalent features:

> The examination of likeness is useful with a view both to inductive arguments and to hypothetical reasonings, and also with a view to the rendering of definitions.[…]It is useful for hypothetical reasonings because it is a general opinion that among similars what is true of one is true also of the rest. If, then, with regard to any of them we are well supplied with matter for discussion, we shall secure a preliminary admission that however it is in these cases, so it is also in the case before us […][145]

"Reasoning by analogy" means inferring an unknown similarity between two objects, from a known analogy between them. Of course, reasoning by analogy is not demonstrative. It might produce hypotheses, or conjectures, and have a useful role in research, but cannot lead to certainty.

Let us consider one famous instance. In 1895 Wilhelm Conrad Röntgen was studying electric discharges in vacuum tubes, when he noticed that a nearby fluorescent plate became bright. The unexpected phenomenon called his attention, and its study led to the discovery of a new kind of invisible penetrating radiation, with peculiar properties. From the very beginning of Röntgen's investigation, it became clear that the new radiation could not be explained by existing theories—it was a puzzle, and that was the reason why it was called "X rays." Röntgen knew it was not light, but his early research on X rays was guided by the search for analogies between the new radiation and light. He checked if it would suffer reflection, refraction, polarisation, diffraction, etc. But he did not assume that the new rays had to exhibit those phenomena.[146]

The kind of thinking behind Ritter's experiments is not analogical thought, in the sense described above. His philosophical presuppositions told him that there should be definite correspondences between the poles of all forces in nature. The specific relationship could be suggested by general philosophical considerations, but in most cases had to be discovered empirically. In any case it was certainly there, waiting to be discovered. In Ritter's mind there was no doubt that there should be a relationship between the electric and magnetic poles and the polarities of oxidation–reduction, red–blue, warm–cold, positive–negative, contraction–expansion, etc.—because all forces of nature arise from the *Urkraft* and are, in some sense, the same thing. This hidden unity is beyond the reach of our experience, but through the emblematic way of thought it is possible to capture its meaning. The essential polarity of nature cannot be reduced to any of the polarities we observe, but it is possible to have a glimpse of its meaning as the common source of all interrelated dualities we observe.

> We have now arrived at a point where we recognize the principles of acidity and alkalinity as principles of electricity. These principles are to be found in all bodies and cannot be separated from their nature. We will certainly not claim on this account that all bodies are acids or bases, for it depends not only on whether these principles

[145] Aristotle, *Topics*, book I, ch. 18, 108b, 6–16.

[146] Roberto de Andrade Martins, *Jevons e o papel da analogia na arte da descoberta experimental: o caso da descoberta do raios X e sua investigacão pré-téorica, Episteme. Filosophia e História das Ciências em Revista* 3 (6) (1998), p. 222–249.

> are present, but also on how they are present. Otherwise, we would be obliged to claim that even the coloured rays of light were acidic or basic. Now this, as a paradox, would not frighten us, but we would become entangled in a great many difficulties. Instead of calling a body with an excess of the positive principle a base, we could say with equal justice that it was violet internally, and that we should not be concerned merely with the outward appearance because there could be causes which impeded the manifestation of the colour. It is indisputable that we should not allow ourselves to be prevented by appearances from seeking the inner principle. Once we have found the principle and, at the same time, seen it revealed in the most varied forms, e.g., as light, as heat, as electricity, as magnetism, etc., it is then time to differentiate precisely between these forms and not to confuse them because of what they have in common.[147]

The emblematic way of thinking is not always explicitly presented in Ritter's and Ørsted's scientific papers, but a careful analysis of some remarks presented by Ørsted will show that it underlies some of the experimental accounts. When Ørsted described Ritter's discovery of the invisible radiation at the violet end of the visible spectrum, he remarked:

> Those experiments can be easily applied to some others, made by the same physicist. He kept his eye in contact for a few minutes with the negative lead of Volta's electric pile, and after this operation all the objects seemed to him red; but after keeping in contact with the positive lead, he saw everything blue.[148]

Notice that Ørsted is establishing a relationship (not an analogy) between widely different classes of phenomena, according to contemporary science: the colours produced by decomposing white light with a prism, and the subjective colours produced by electric stimulation of the eye. It is also remarkable that Ørsted, following Ritter did not conclude that negative electricity was related to red, and positive electricity to blue, but the opposite:

> This great discovery was soon joined by a second, that of the effect of galvanism on the eye. If *the nerves of the eye* have been put into the positive state, all objects are seen with a *red* color (in darkness) and *larger than they are otherwise seen*, but if they have been put into the negative state, all objects appear *blue* and *smaller* than usual. If we recall that the positive pole of the battery is the oxidizing one, the negative the deoxidizing one, and that the blue color lies closest to the violet in the spectrum, the connection between this and the previous discovery becomes very clear to us. Oxidation and the red pole of the spectrum, deoxidation and the violet pole are associated with each other.[149]

In a footnote, Ørsted explained that, actually, it was necessary to put the *negative* end of the pile into contact with the eye to produce the sensation of red colour, but that in this case one should not explain the effect as due to negative galvanism, but as due to the positive galvanism acquired by the retina and optical nerves:

> Actually, [all objects are seen with a *red* colour] if the negative pole has been kept in contact with the eyeball for some time. The liquid in the eye, like any other liquid, must polarize, and therefore, if it becomes negative on the outer surface, the inner becomes positive. This explanation stems from the astute Dr. Reinhold in Leipzig, who has also repeated Ritter's experiments and found them completely confirmed.[150]

[147] Ørsted, "The series of acids and bases," (1806), in *Selected scientific works…*, p. 239.
[148] Ørsted, *Expériences avec la pile électrique…*, p. 410.
[149] Ørsted, "A review of the latest advances in physics," (1803), in *Selected scientific works…*, pp. 107–108.
[150] Ibid. p. 107.

A similar explanation appeared in his French paper:

> One should remark that when the outside of the eye is in a negative state, the retina and the optic nerve become positive, and vice versa; because the eye is full of a fluid, in which there occurs the same distribution of electricity that happens in water and other fluids. Therefore, it is in a positive state that the optic nerve perceives all objects with a red color, and in the negative state they appear with a violet color.[151]

Only accepting this interpretation was it possible to establish a coherent relationship between electricity, chemical effects and color: both positive electricity and the red light produce oxygenation, and both negative electricity and violet light produce reduction (Ørsted, 1803b, p. 410). The careful reinterpretation of the experimental situation was required because Ritter and Ørsted were not describing mere analogies but were trying to unravel the inner correspondences between different manifestations of the *Urkraft*.

16. THE ELECTRIC POLARITY OF THE EARTH

Now, if we return to Ritter's researches on magnetochemistry and their context, as described by Ørsted, it will become clear that his steps were guided by the above described emblematic way of thinking.

Ørsted's first communication to the French Academy was a report on Ritter's "secondary pile." Ritter found out that it was possible to build an electric accumulator using a pile made of a single metal. He built it with a series of metallic plates intermingled with paper wet with salt water. After this secondary pile had been connected to a Voltaic pile for some time, it became a source of electricity. This was a very interesting finding because Ritter had been able to induce an electrical polarity upon a system that was completely symmetrical.

This discovery was well received by the French *savants*, and Ørsted published his report at the *Journal de Physique, de Chimie, d'Histoire Naturelle et des Arts*.[152] However, when he was preparing this communication he received a new letter from Ritter telling him about his fresh discovery of the "electric poles" of the Earth, and Ørsted included this information as a *post-scriptum* to his paper.

During 1803 Ritter had published two papers where he discussed a possible relation between some atmospheric phenomena (including storms and *aurora borealis*) and electricity or magnetism.[153] He pointed out that there were periodic variations of several phenomena that could establish a relationship between them.

[151] Ørsted, *Expériences sur la pile électrique*.., p. 410.

[152] Ørsted, *Expériences sur un appareil*…. A shorter version of Ørsted paper was translated in: Ørsted, "Abstract of a memoir on galvanism, sent to the National Institute by Mr. Ritter, of Jena," *Journal of Natural Philosophy, Chemistry, and the Arts*, 7 (1804), pp. 288–291.

[153] Johann Wilhelm Ritter, *Auszuege aus Briefen verschiednen Inhalts an der Herausgeber. 1. Von Herrn J. W. Ritter, Annalen der Physik* 15 (1803), pp. 106–110; Ritter, *Einiges ueber Nordlichter und deren Periode, und ueber den Zusammenhang des Nordlichts mit dem Magnetismus, und des Magnetismus mit den Feuerkugeln, dem Blitze und der Electricitaet, Annalen der Physik* 15 (1803), pp. 206–226. John Robinson and other authors had already reported that the *aurora borealis* acted upon the magnetic compass, deviating it from the meridian. See Mottelay, *Bibliographical History of Electricity and Magnetism*…, p. 309.

In those studies about atmospheric phenomena Ritter had already hinted that the Earth should have an electrical polarity. Then, using his secondary pile (or accumulator), he noticed that the device exhibited weak effects even when it had never been linked to a Voltaic pile. Those effects could be observed using a frog as a sensor. When the secondary pile was put in a vertical position, the upper end of the accumulator acquired a positive charge, and the lower one a negative one. He supposed that this effect was due to an external electrical field produced by the Earth, and moved the secondary pile to several different positions, to find out the direction of the field. Keeping the device in the plane of the magnetic meridian, the effect was maximum when the pile was tilted to the North, and formed an angle of about 30 degrees with the vertical direction. When the secondary pile was put in the horizontal position, in the North–South direction, the North end acquired a positive charge. The effect increased when this extremity of the device was turned about 30 degrees to the East. His conclusion was that the Earth has electric poles and electric meridians. According to Ritter, those poles affect atmospheric phenomena (such as storms) and they produce an electrical polarity in animals, plants, men, stones and all objects.[154]

In his following letter to Ørsted, Ritter described new experiments using a secondary pile made of 1,000 plates. The device was about 4 meters long and it was difficult to manipulate. The experiments had to be done outdoors, and of course it was very difficult to produce repeatable results with frogs in those conditions. Ritter also told Ørsted that he had been successful in building something that could be described as an electric compass, that pointed towards the electric poles of the Earth. He took a thin gold wire and connected its ends through moist conductors to a 200-elements voltaic pile.[155] After five minutes the gold wire was put on a pivot similar to those of magnetic compasses and was protected from air drafts. According to Ritter, the gold needle turned to the electric poles of the Earth.[156]

Ritter's experiments with the gold wire were witnessed by Christian Bernoulli, who published a positive report about them.[157]

Ørsted usually attempted to replicate Ritter's experiments. In the specific case of the electric compass, he repeated it using a platinum wire, but the experiment did not succeed. He commented: "I would not dare to doubt Mr. Ritter's experiment because of that; I have repeated it without being completely aware of its details."[158]

It is rather curious that in later experiments Ritter built a lengthy (six inches long) bimetallic needle (half its length made of zinc and the other half made of silver) and described that this needle behaved as a magnet, the zinc end pointing

[154] Ørsted, *Expériences sur un appareil…*, pp. 364–365.

[155] Ibid. p. 365. Ritter had noticed that it was possible to produce an electrical polarity upon metals by this method.

[156] Ritter published his first claim concerning this effect in *Auszuege aus Briefen…*, but he did not provide a description of his experiments. His account was published in 1805: Ritter, *Das electrischen System der Körper* (Leipzig: C. H. Reclam, 1805), pp. 383–384.

[157] Christian Bernoulli, "New galvanic experiments by M. Ritter. Extracted from a letter from M. Christ. Bernoulli," *Philosophical Magazine* 23 (1806), 51–54.

[158] Ørsted, *Expériences sur un appareil …*, pp. 364–365.

to the North and the silver end pointing to the South. Besides that, the needle was also acted on a magnet, in the same way as a magnetic needle.[159] Ritter's 1803 experiment inspired Jean Nicholas Pierre Hachette and Charles Bernard Desormes to attempt an interesting experiment. In 1805 they built a huge copper-zinc pile containing 1,400 metal plates. The length of the pile was about 1 metre. It was put in a horizontal position in a small wooden boat, floating in still water. They expected the boat to turn to the electrical poles of the Earth, but no motion was observed.[160]

In the following years (1804–1806) Ritter continued to compare magnetism to electricity. He published a book where he described new evidence for the electric poles of the Earth he had discovered in August 1803. He used several needles made of gold, silver or copper submitted for a few minutes to the voltaic pile.[161] One of the extremities of the needles pointed towards some direction between north-north-west and north-west.

Ritter described new relations between electricity and magnetism. He built a compass with a long silver-zinc needle and reported that it would behave as a magnet, aligning itself in the direction of the magnetic meridian. The zinc end approached to the North and the silver end to the South. The north pole of an iron magnet would attract the silver end and would repel the zinc end. Therefore, positive electricity pointed to the North magnetism, and negative electricity corresponded to South magnetism.[162] The effect was stronger when Ritter replaced the silver part of the needle with carbon or lead. Therefore, when two different metals (or conductors) are connected, they bring forth a polarity that could produce both magnetic and electric effects.

When Ritter's researches on magnetochemistry are regarded in this context, it is possible to perceive that they were not isolated empirical findings suggested by a loose analogy. They must be considered as part of a research programme guided by strong philosophical presuppositions (unity of all forces of nature, basic polarity of forces and their effects) and an emblematic way of thinking. All this led Ritter to search for definite relations between the magnetic poles and the other polarities of nature—electrical, chemical, etc. Ørsted interpreted those results as a demonstration that magnetism and electricity are produced by the same basic forces:

> […]the same forces which manifest themselves in electricity also manifest themselves in magnetism, although in another form. Attractions and repulsions are the same in magnetism as in electricity, opposite forces attract, like ones repel each other. Through magnetism two pieces of iron can be made to produce the same effect on a prepared frog as two different metals. If an iron wire is magnetized, the end which becomes the south pole will become more combustible than it was before, but the one that becomes the north pole will lose some of its combustibility. Ritter has convinced us of this

[159] Ritter, *Das electrische System der Körper…*, p. 379.

[160] When a weakly magnetised iron bar of the same weight was put in the same boat, it soon acquired the North–South direction. Jean Nicolas Pierre Hachette, "*Experience sur le magnetisme de la pile electrique*," *Correspondance sur l'Ecole Impériale Polytechnique, a l'usage des éleves de cette Ecole*," 1 (1805), pp. 151–153. See also Hachette's later account of his experiment: Hachette, *Sur les expériences electro-magnétiques de M.M. Ørsted et Ampere, Journal de Physique, de Chimie et d'Histoire Naturelle* 91 (1820), pp.161–166, at 165.

[161] Ritter, Johann Wilhelm. *Das electrische System der Körper…*, pp. 383–384.

[162] Ibid. 379–380.

> through many experiments whose validity can easily be ascertained through experience. Consequently, the same forces are at work in electricity and magnetism.[163]
>
> The remaining similarities between magnetism and electricity are so great that we need only remove the apparent contradictions in order to accept the identity of the forces in them. […] Ritter has also found that magnetized iron wire is less oxidizable at its northern end and more oxidizable at its southern end than iron, but iron or soft steel must be used here because harder steel produces less activity and, in fact, in the reversed order due to its poorer conduction and its corresponding smaller quantity of force. Under similar conditions, muscular contractions are also induced in a prepared frog if two opposite poles of a magnetized iron wire are connected to it in such a way that a closed circuit can be formed. The wires must be magnetized by means of relatively strong magnets. These experiments are still somewhat disputed by physicists, but so many have been successful that it is not easy to assume a false conclusion. […] Therefore, all the functions which can be demonstrated in electricity can also be observed in magnetism: attractions and repulsions, chemical difference, effects on the living animal body, the production of light.[164]

In 1805, Ørsted used Steffens' ideas to connect electricity, magnetism, the "four chemical elements" (carbon, nitrogen, oxygen, and hydrogen) and the four principal geographical directions:

> […] Oxygen and hydrogen, carbon and nitrogen are also here revealed as the 4 chemical elements, the two former corresponding to the contrast in electricity, the two latter to that of magnetism, as our great natural philosopher Steffens first proved. Carbon and nitrogen appear in chemical action, like magnetism in nature, in internally determined forms; oxygen and hydrogen, like electricity, as eternally mutable, striving towards new forms.[165]

Ørsted remarked that even the "magnetic" pair (carbon and nitrogen) had also an electrical polarity: "The substances containing carbon form the negative, the substances containing nitrogen the positive elements."[166]

Carbon and nitrogen would be related to north and south, as shown by geology: "To the north, carbon is prevalent, which is indicated by the enormous number of forests, peat bogs, coal, etc., but to the south, nitrogen is found more often, which is demonstrated by many coral mountains."[167] Next, he presented the complete symbolic relation between electricity, magnetism, the chemical elements, night and day, animal and vegetable, winter and summer, and the four cardinal directions:

> The day is deoxidizing, the night oxidizing. The same relation reappears on a larger scale between summer and winter. Briefly, a constant process of combustion and reduction proceeds from east to west, the same electro-chemical process which we have demonstrated in the animal and vegetable kingdoms.
>
> Steffens's glorious idea to regard oxygen and hydrogen as representative of east and west, and carbon and nitrogen as representatives of north and south is then confirmed in the most perfect way, however paradoxical it might appear to all those who are not informed about recent physics.[168]

[163] Ørsted, "New investigations into the question: What is chemistry?," (1805), in *Selected scientific works …*, p. 196.

[164] Ørsted, "View of the chemical laws of nature obtained through recent discoveries," (1812), in *Selected scientific works…*, p. 379.

[165] Ørsted, "On the harmony between electrical figures and organic forms," (1805), in *Selected scientific works…*, p. 189.

[166] Ibid.

[167] Ibid. p. 190.

[168] Ibid.

Although Ørsted did not associate Steffens' ideas to Ritter's experiments, one may notice the agreement between their conclusions concerning the East–West electrical polarity of the Earth.

17. ØRSTED AND NATURPHILOSOPHIE

The previous sections attempted to show that Ritter's researches on the polarities of electricity, magnetism, and other forces, can be regarded as a clear example of an empirical quest guided by the assumptions and way of thinking promoted by Schelling's *Naturphilosophie*. Ørsted's uncritical dissemination of Ritter's ideas and results seems to point out that he accepted all those beliefs in his early scientific career.

At this time, Ørsted was presenting to the German-speaking public Winterl's chemistry. As Kenneth Caneva has convincingly shown, Ørsted modified Winterl's ideas so as to fit his own beliefs[169]: "To a very considerable extent, the Winterl who has come down to us *is* the Ørstedized version closely associated with the dynamical *Naturphilosophie* Winterl himself stood apart from." It is reasonable to assume that, at the same time, when Ørsted presented Ritter's ideas, he would change and adapt them if they did not fit his own beliefs. Hence, I assume that whenever Ørsted is describing Ritter's ideas and experiments in the early years of the 19th century, he is describing what *he* accepts as true.

Anja Jacobsen has already stressed that it is difficult to distinguish between Ritter's and Schelling's influences upon Ørsted:

> It is quite difficult to distinguish precisely which influence on Ørsted's ideas stems from Ritter's electrochemistry and which from Schelling's *Naturphilosophie*. Historians of science generally seem to be unclear about how Ritter's and Schelling's ideas stand in relation to each other; who influenced the other? However, it is a fact that Ritter's ideas are more tangible and related to actual experiments whereas Schelling's ideas are on a more philosophical framing level, although they are sometimes quite similar to each other.[170]

Ørsted rejected the work of purely speculative philosophers who were not acquainted with experimental work.[171] In this respect, Schelling's work did not seem to him adequately scientific. This does not entail, however, that he was not influenced by Schelling.

Although several authors (including Andrew Wilson) have already presented clear substantiation concerning the relation between Ørsted and Schelling, let me add some more evidence.

In his 1799 work on *Fundamentals of the metaphysics of nature*, Ørsted followed Kant in his introduction of the basic forces of matter (attraction and repulsion) as necessary conditions of the existence of matter of finite size:

> The expansive force prevents the attractive force from reducing the extent of matter to zero, and the attractive force prevents the expansive force from giving matter an

[169] Caneva, "Ørsted's presentation of others'—and his own—work," (*this volume*).
[170] Jacobsen, *Between Naturphilosophie and tradition…*, p. 47.
[171] Ibid. p. 71–73.

> infinitely large extent. They work in opposition to each other and produce motion in opposite directions so that one may be regarded as *negative* when the other is regarded as *positive*.[172]

Notice that, here, Ørsted adopted a view similar to Kant's and introduces "positive" and "negative" just as relative terms, without ascribing one of them to expansion and the other to contraction. At this time, Ørsted did not accept Schelling's ideas:

> The two attempts to build a chemistry on the basis of the critical metaphysics of nature that I am familiar with are so unsuccessful that they have brought their authors into the most evident contradiction with its foundations. The first to make an attempt of this kind is, as far as I know, the above-mentioned Eschenmayer, who builds it on the doctrine of the relation between the fundamental forces of matter which we have seen above. In his *Ideen zur Philosophie der Natur*, Schelling has adopted the same doctrine and developed it more precisely. As the theory of the former philosopher is false from its first foundation, the chemistry which he has based upon it is also false and is in conflict with the basic ideas of dynamics. As Schelling tries to develop the same chemical theory on other grounds, I only want to demonstrate its incorrecteness by means of a few observations.[173]

Towards the end of this work, Ørsted mentioned two of Schelling's books: *Ideen zu einer Philosophie der Natur*, and *Von der Weltseele*, and remarked that "these two books certainly deserve attention because of the beautiful and grand ideas which are found in them, but the insufficiently rigorous method, whereby the author adds empirical theorems without distinguishing them adequately from a priori theorems, deprives the book of much of its value, in particular because the empirical theorems that he adduces are often completely false."[174] At this time, it was impossible to classify Ørsted as a follower of Schelling's ideas.

Shortly afterwards, however, Ørsted's opinion about Schelling began to change. In the same year (1799) he published his "Dissertation on the structure of the elementary metaphysics of external nature" where he presented a favourable attitude:

> This essay of mine was almost finished when Schelling's excellent *Erster Entwurf einer Naturphilosophie* arrived here, so I could not use it in this place, which I certainly regret; in any case, his book contributes much more to the higher than to the elementary metaphysics of nature. What I have tried to establish in this dissertation about the force of cohesion is in accordance with the views of this philosopher; I have not, however, derived these findings from his book […][175]

Although Ørsted highly praised Kant, at some places he openly criticised him: "[…] although I originally intended to follow in Kant's footsteps as far as this subject is concerned, when I thought it over more carefully I was forced to leave that trail."[176]

Schelling's influence upon Ørsted became stronger after 1802. In 1802, Ørsted's ideas were already regarded as related to *Naturphilosophie*, and this was a cause of concern around him. In Berlin, during his continental travels (1801–1802),

[172] Ørsted, "Fundamentals of the metaphysics of nature," (1799), in *Selected scientific works…*, §39, p. 61.

[173] Ibid. §67, p. 71.

[174] Ibid. §80, p. 77.

[175] Ørsted, "Dissertation on the structure of the elementary metaphysics of external nature," (1799), in *Selected scientific works…*, pp. 79–80.

[176] Ibid. p. 84.

he defended *Naturphilosophie* against the criticisms of Alexander Nicolaus von Scherer.[177]

One decade later, Ørsted contrasted Kant's and Schelling's contributions to physics in a very suggestive way:

> The progress of philosophy in the eighteenth century has not been without influence on general physics. The perspicacity of Immanuel Kant liberated it from the atomistic system, which, though of speculative origin, was made the basis of experimental physics. F. W. J. Schelling created a new natural philosophy, the study of which must be important to the empirical student of nature and must both inspire many new ideas in him and also prompt him to re-examination of much that was previously considered unquestionable.[178]

Notice that Ørsted did not emphasise Kant's contribution to the dynamical viewpoint, but only his anti-atomism. Notice also that his words present Schelling's contribution as much more relevant than Kant's.

It is also relevant to point out that Ørsted ascribed to Schelling—not to Kant—the attempt to find the unity behind all phenomena:

> […] As none of the physical processes is completely isolated but is connected with others, it follows that the science which we are discussing here cannot be divided into two parts, like physics itself, but that it must constitute a single, organic science, in relation to which experimental physics only serves as a means. We have fragments of such a science, for example, physical astronomy, geology, and meteorology, but the complete science does not exist yet and can never be reached by the path of experience. It is well-known that Schelling, through speculation, has produced an attempt which, as such, is of incalculable value, but the combined efforts of a great number of blessed geniuses are probably required for the accomplishment of this task.[179]

In his writings, Ørsted not often refers to Schelling by name. However, there is a very strong influence that can be noticed when one compares the content of their ideas. Let us show just one instance: Ørsted's description of magnetism and electricity as related to one and two dimensions:

> A brief outline of what we know about the effects of these forces is sufficient to show us the possibility that all the different forces of nature can be traced back to those two fundamental forces. How could there be three more different effects than heat, electricity and magnetism! Yet, all of these are due to the effect of the same fundamental forces, only in different forms. Magnetism acts only in a *line* which is determined by the two opposite poles and the intermediate point of equilibrium. Purely electrical effects only follow *surfaces*. Heat works equally freely in *all directions* in a body.[180]

It is possible to find very similar ideas in Schelling: "[…]magnetism, as a process, as form of activity, is the process of length, electricity the process of breadth, just as the chemical process, on the other hand, is that which alone affects cohesion or form in all dimensions, and hence in the third."[181] Or, more fully:

[177] Jacobsen, *Between Naturphilosophie and Tradition*…, pp. 18, 40–42.

[178] Ørsted, "First introduction to general physics," (1811), in *Selected scientific works*…, p. 305.

[179] Ørsted, "New investigations into the question: What is chemistry?," (1805), in *Selected scientific works*.., p. 199.

[180] Ibid. p. 197.

[181] Schelling, *Ideas for a philosophy of nature*, …, p. 137.

> What was cohesion and magnetism in the first and second potency, returns here, after the ideal principle has identified itself with matter *for the first dimension*, as the formative impulse, as reproduction. What there presented itself as relative cohesion, or electricity, is here, in the absolute identification of form and matter *for the second dimension*, raised to irritability, to the living power of contraction. Finally, where the light takes the place of matter altogether, and presses into the *third dimension*, so that essence and form in this way become wholly one, the chemical process of the lower potency passes over into sensibility, into the inner absolute formative power.[182]

Taking into account all evidence presented here, it seems that Ørsted was strongly influenced by Schelling's *Naturphilosophie* during the first decade of the 19th century. At times this influence was direct. More often, however, he was influenced through Ritter's work.

18. CONCLUDING REMARKS

In the early decades of the 19th century no magnetochemical effect had become reproducible—or, in Ian Hacking's terminology, no magnetochemical phenomenon had been *created*:

> To experiment is to create, produce, refine and stabilize phenomena. If phenomena were plentiful in nature, summer blackberries there just for the picking, it would be remarkable if experiments didn't work. But phenomena are hard to produce in any stable way. That is why I spoke of creating and not merely discovering phenomena. That is a long hard task.[183]

During that period, the search for chemical effects of magnetism was driven by two different impulses. The first influence, that acted upon Ritter (and Arnim), was the belief in a fundamental unity of all forces of nature and the search for definite relationships between the polarities of those forces. Ritter's magnetochemical investigations can only be fully understood in the philosophical context of Schelling's *Naturphilosophie*, that guided his experimental research. By Ritter's personal influence, and due to his sharing the main Romantic tenets, Ørsted came to accept all the effects he described as genuine, and helped to disseminate Ritter's discoveries.

Ritter's magnetochemical researches were criticised by Paul Erman in 1807, as described above. It is noteworthy, however, that Erman's attack was not an isolated and neutral piece of scientific work. Erman's papers were published in the *Annalen der Physik*, where there appeared, at the same time, severe attacks against *Naturphilosophie*. The speculative method defended by Schelling was condemned by Ludwig Wilhelm Gilbert, the editor of the *Annalen der Physik*. Gilbert asserted that the vogue of galvanism had passed. He strongly criticised the abuse of "duality" and "polarity" in all fields of chemistry and physics. Erman added that Schelling's *Naturphilosophie* was a greater blame to the Germans than twenty defeats by Napoleon.[184]

[182] Ibid. p. 138.

[183] Ian Hacking, *Representing and Intervening. Introductory topics in the philosophy of natural science* (Cambridge: Cambridge University Press, 1983), p. 230.

[184] Stuart Strickland, "Galvanic disciplines: the boundaries, objects, and identities of experimental science in the era of Romanticism," *History of Science* 33 (1995), pp. 449–468, at 452; Armin Hermann, "Unity and metamorphosis of forces …, p. 56.

Notice that Gilbert's journal had published many papers of the Romantic physicists—including Ritter. It seems that Ritter's speculations about the divining rod triggered Gilbert's criticism against this approach in 1807.[185]

The attack against Ritter and *Naturphilosophie* in 1807 by Gilbert and Erman was successful, and for many years no new attempt was made to find a relation between magnetism, galvanism, and chemical phenomena. Ørsted was probably one of the very few people who in the 1810s still entertained expectations concerning the unity of all forces of nature.

Maschmann's work was not inspired by philosophical beliefs. It was due to an accidental observation. It seems that Maschmann, Hansteen, and Ørsted felt insecure about the reality of these effects before 1820, since they did not publish any account of those experiments. Perhaps the criticism suffered by Ritter one decade earlier had some bearing on this cautious silence.

After 1820 the situation changed, and many researchers turned to magneto-chemical experiments, not as the result of new philosophical influences, but as an effect of the unexpected discovery of electromagnetism. The situation was similar to what happened from 1896 onwards, after the discovery of X-rays. I agree with Oliver Lodge, who remarked that new discoveries usually produce general doubts about accepted knowledge, and speculative activity.[186]

Up to 1812 Ørsted had a firm assurance that Ritter's experiments had demonstrated the relation between galvanism and magnetism. As remarked by Anja Jacobsen, the very name of the book he published at this time (in French: *Recherches sur l'identité des forces chimiques et électriques*) shows that he still accepted one of the central ideas of Schelling's *Naturphilosophie* at this time.[187]

It is difficult to ascertain whether Ørsted's later denial of Ritter's findings was due to his most intimate conviction that Ritter was a poor experimenter, or a response to changing cultural forces. In 1830 he was content to accept Maschmann's and Hansteen's experiments, although the influence of magnetism upon the formation of Diana's tree was controversial.

This paper did not directly address the general problem of Ørsted's relation to Kant. It is possible that in his earliest and later periods Ørsted was more strongly associated to Kant's ideas than to Schelling's, as claimed by Dan Christensen.[188] The contention of this paper is that during his early scientific career, in the course of publishing his accounts of Ritter's experimental researches on the polarities of nature, Ørsted's ideas had a clear *Nature-philosophical* inspiration. Ritter's search for definite relations between the magnetic poles and the polarities of other natural forces cannot be understood apart from his fundamental philosophical beliefs. Ørsted's presentation of Ritter's ideas and experiments, together with his later favourable comments upon those researches, is a strong evidence that he was also guided by very similar ideas at that time. Ritter's emblematic way of thinking,

[185] Kaiser, "Symmetries in Romantic physics…, p. 86.

[186] Oliver Lodge, "The discovery of radioactivity, and its influence on the course of physical science (Becquerel memorial lecture)," *Journal of the Chemical Society* 101 (1912), 2005–2031.

[187] Jacobsen, *Between Naturphilosophie and tradition…*, p. 149.

[188] Dan Charly Christensen, "Ørsted's concept of force," (*this volume*).

shared by Ørsted, also points out a Romantic influence that cannot be ascribed to Kant. Altogether, this specific case study supports the contention of a strong influence of Schelling's *Naturphilosophie* in Ørsted's early scientific career.

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[189] This notice was reproduced in a number of journals: *Aus dem Intelligenzblatte der Allgem. Litterat. Zeit. Den 5ten Febr. 1806, Annalen der Physik* 22 (1806), pp. 223–224; "Extract of a letter to professor Pictet, from a Correspondent at Munich, upon some galvanico-magnetic experiments recently made by M. Ritter," *Philosophical Magazine* 25 (1806), pp. 368–369, 1806; *Estrato d'una lettera scritta da Monaco in Baviera al Sig. Prof. Picted di Ginevra su alcuni sperimenti galvanico-magentici fatti recentemente dal Sig. Prof. Ritter, Nuova Scelta d'Opuscoli* 1 (1806), pp. 334–336.

[190] Cf. the Italian version of the letter see Bernouolli, Christian. '*Scoperte galvaniche del Sig. Ritter estratte da una lettera del Sig. Cristoforo Bernoulli. Nuova Scelta d'Opusculi Interessanti sulle Scienze e sulle Arte* **1**: 201–202, 1806.

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[192] This periodical had two different titles. It was also called *Jahrbuch der Chemie und Physik*, from vol. 30 onwards (with a new numbering of the volumes). *Journal für Chemie und Physik* **56** corresponded to *Jahrbuch der Chemie und Physik* **26**.

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[199] Cf. the French translation of this article: *Note sur l'influence mutuelle du magnétisme et des actions chimiques*. *Bibliothèque Universelle des Sciences, Belles Lettres et Arts* **1**: 22–29, 1830.