Philosophy and the Chemical Revolution after Kant

Michela Massimi

1. Introduction

The term *Naturphilosophie* denotes a philosophical movement that developed in post-Kantian Germany at the end of the eighteenth century. Fichte and Schelling belonged to this intellectual movement, which had strong cultural links both with Romanticism (including Goethe, Novalis, and Hölderlin) and post-Kantian Idealism. As with any hybrid and transient cultural movement, it is difficult to define *Naturphilosophie* in terms of a specific manifesto or well-defined cultural program. The term came to denote a fairly broad range of philosophical ideas, whose seeds can be traced back, in various ways, to Kant's philosophy of nature. Yet, *Naturphilosophen* gave a completely new twist to Kant's philosophy of nature, a twist that eventually paved the way to Idealism.

The secondary literature on *Naturphilosophie* has emphasized the role that the movement played for the exact sciences of the early nineteenth century. In a seminal paper (1959/1977, 66-104) on the discovery of energy conservation Thomas Kuhn gave *Naturphilosophie*(and, in particular, F. W. J. Schelling, credit for stressing the philosophical importance of conversion and transformation processes. These ideas played an important role in the nineteenth-century discovery (carried out independently by Mayer, Joule, and Helmholtz) of the interconvertibility of thermal energy into mechanical work, as well of electricity into magnetism (by Ørsted and Faraday). Schelling, is said to have inspired Hans Christian Ørsted's pioneering experiments on electromagnetism in the early 1820s, and even Michael Faraday's later discoveries of electromagnetic induction at the Royal Institution of Great Britain. In this chapter, we leave aside the question as to whether the connection between Schelling and Faraday is historically correct. More generally, we do not address the relevance of *Naturphilosophie* to the history of electromagnetism. There has been a historiographical debate on both these questions, and enough ink has already been spilled on them.[1]

Instead, our task in this chapter is to review some core ideas emerging from Schelling's philosophy of nature, with a twofold aim in mind. First, we should get clear on how, once in Schelling's hands, key aspects of Kant's philosophy of nature were transformed into a radically new philosophy of nature. Second, this exercise can throw light on some underappreciated effects of Schelling's philosophy of nature on the *cultural* *milieu* of Jena at the turn of the nineteenth century, where important discoveries and reflections on electrochemistry took place. With regard to the second point, Schelling, and *Naturphilosophie* in general, have often been accused of being too speculative, too obscure, too alien to the experimental method to ever be in the position of exercising any genuine influence on the sciences of the time. In what follows, I set the record straight about some key themes in Schelling's philosophy of nature, and how they informed (and were in turn informed by) the electrochemistry of the time. Schelling needs to be understood in the historical context of the so-called Chemical Revolution, where discoveries about electricity and controversies surrounding galvanism played a role in the demise of the theory of phlogiston and in the final victory of Lavoisier's system of chemistry.

At a philosophical level, Schelling's main contribution was to *naturalize* Kant's notion of the unconditioned and to transform it into an object of empirical investigation for *Naturphilosophie*. In so doing, Schelling took Kant's important insight about the *perspectival* nature of human knowledge (qua knowledge of phenomena, and not noumena) and turned it upside down: "*Empiricism extended to include unconditionedness is precisely philosophy of nature*" (Schelling 1799/2004, 22). By making the unconditioned an object of empirical investigation, a path was opened to German Idealism. This development provides a framework for understanding the interchangeability of electrical and chemical phenomena in a way that — however unscientific and speculative it may appear to us—nonetheless played an important role at the time in central debates surrounding the rise of the new chemistry of Lavoisier.

2. Schelling's *Naturphilosophie*.

In *Ideas for a Philosophy of Nature* (1797) and *First Outline of a System of the Philosophy of Nature* (1799) Schelling laid out the foundations for a new philosophy of nature. Schelling's *Naturphilosophie* has been historically read as the triumph of speculative physics and aprioristic reasoning, in its declared intent of explaining the entire realm of nature in terms of opposite forces or polarities, from inorganic to organic. Because it was thought to be scientifically wrong-headed and philosophically aprioristic, Schelling's *Naturphilosophie* has often been shunned in the history of scientific philosophy (it comes perhaps as no surprise that only recently, in 2004, an English translation of his 1799 *First Outline* was made available). Even the scientific discoveries that can be traced back to Schelling's intellectual world (such as Ørsted's discovery) are typically kept separate from the unpalatable speculativeaspects of Schelling's reflections on nature.[2] There is no denying that Schelling's philosophy of nature promoted a speculative physics that is at some distance from actual scientific practice and the history of science. Yet, the historiographical tradition that has relegated Schelling among the aberrations of post-Kantian philosophy of nature is probably the product of reading Schelling inappropriately through the lenses of the neo-Kantianism and the logical empiricism of the late nineteenth century and early twentieth century. Schelling's speculations on polar forces became synonymous with aprioristic, non-experimental, speculative physics, the direct opposite of the kind of non-hypothetical, experimental physics of Newtonian origins that Kant celebrated in his *Metaphysical Foundations of Natural Sciences* and other writings on natural science— exactly the kind of writings that Helmholtz and the Marburg school rediscovered and championed in the nineteenth century.

In Sections 3-5, I briefly (and very selectively) present a few important themes in Schelling's philosophy of nature. I focus on the *First Outline* for the exposition of these themes because this text provides probably the most thorough exposition of Schelling's early philosophy of nature, which appeared at a critical moment for the sciences of the time and the debate surrounding galvanism and electrochemistry.[3] In Section 6, I turn to the history of electrochemistry and in particular to Johann Ritter's experiments, which help in clarifying the intellectual backdrop for Schelling's reflections on nature. In Section 7, I make some concluding remarks about how Schelling's themes bear upon the blossoming area of electrochemistry at the end of the eighteenth century, and shed light on the controversy surrounding the so-called Chemical Revolution.

3. The Unconditioned in Nature. Autarchy and Autonomy of Nature

One of the most striking and better known aspects of Schelling's natural philosophy is his reaction against the Kantian division between theoretical reason and practical reason. While Kant regarded positive access to the unconditioned as belonging to the realm of practical reason (in particular to the ideas of reason, i.e. God, soul, and the world as a whole), Schelling boldly relocated the unconditioned in the realm of theoretical reason, in the form of the scientific knowledge of nature. Let us then start with a short summary of Kant's view of the unconditioned.

Kant's most thorough discussion of this point takes place in the *Critique of Pure Reason*, in the Transcendental Dialectic under the heading, "The Antinomy of Pure Reason". There, in "The System of Cosmological Ideas", Kant famously argued that if a conditioned is given, then reason presumes that "**the whole sum of conditions, and hence the absolutely unconditioned, is also given**, through which alone the conditioned was possible" (B436; emphasis in the original). Hence, if we take, for any conditioned, the series of conditions—each subordinated to the next one—and we either ascend in this series, or, vice versa, we descend from each conditioned to its series of consequences, then we get what Kant calls either a **regressive** or a **progressive** synthesis. By taking in turn the four headings of the categories, and the notion that the "**unconditioned** is always contained **in the absolute totality of the series** if one represents it in imagination" (B444), Kant derived "four cosmological Ideas" in the regressive synthesis of the manifold in appearance to an unconditioned individual (B445). The four cosmological ideas are of (1) a world that has a beginning in time and a spatial limit, (2) a whole that is simple in its parts ,(3) a causality that begins with self-activity (freedom) , and (4) natural necessity (with respect to modal categories). In this context Kant introduced an important distinction:

> We have two expressions, **world** and **nature**, which are sometimes run together. The first signifies the mathematical whole of all appearances and the totality of their synthesis in the great as well as in the small, i.e. in their progress through composition as well as through division. But the very same world is called nature insofar as it is considered as a dynamic whole and one does not look at the aggregation in space or time so as to bring about a quantity, but looks instead at the unity in the **existence** of appearances. Now the condition of what happens is called the cause, and the unconditioned causality of the cause in appearance is called freedom; the conditioned cause in the narrower sense, on the contrary, is called the natural cause. The conditioned in existence in general is called contingent, and the unconditioned necessary. The unconditioned necessity of **appearances** can be called natural necessity (B446-7, A419).

And in the footnote appended to this passage, Kant added:

> "Nature" taken adjectivally (*formaliter*) signifies the connection of determinations of a thing in accordance with an inner principle of causality. Conversely, by "nature" taken substantively (*materialiter*) is understood the sum total of appearances insofar as these are in thoroughgoing connection through an inner principle of causality.

> In the first sense, one speaks of the "nature" of fluid matter, of fire, etc. and employ this world adjectivally; conversely, if one talks about the "things of nature" then one has in mind a subsisting whole (A418-9/B446).

Thus, for Kant, if nature is regarded as a "dynamic whole" in accordance with the unity in the **existence** of appearances, the unconditioned causality of this series of causes in appearances is called freedom, and the unconditioned necessity of appearances is called "natural necessity". Natural necessity for Kant arises by taking nature *materialiter* as "the sum total of appearances insofar as these are in thoroughgoing connection through an inner principle of causality." By contrast, causality as a principle of the understanding can only tell us how to connect determinations of things in a lawlike way (e.g. how the "nature" of fire may be connected with the "nature" of winds in virtue of their respective determinations being *grounded* in the same causal power, for example in the repulsive force).[4]

But when causality is extended from the understanding to reason so as to think of the sum total of all appearances as being united in existence (a "subsisting whole") according to an unconditioned causality, one thinks of the world as conditioned by freedom. Now, such unconditioned causality for Kant is an "**intelligible** condition" which does not belong to the series of appearances as a member, and hence can be thought of as "**empirically unconditioned**" (A531/B559) without interrupting or violating in any way the series of specific empirical conditions for any given appearance in the series.

In Schelling's hands, what Kant calls the empirically unconditioned becomes the "Unconditioned in Nature". In Schelling's *First Outline,* right at the outset in the *First Division,* Schelling introduces the notion of "The Unconditioned in Nature". Building on, but also going beyond, Kant's aforementioned remarks, Schelling declares that the unconditioned does not belong to any individual being or individual natural object as such, because any individual natural object is only a "determinate form or limitation" of *being itself,* and *being itself* is nothing other than "originary activity" (Schelling 1799/2004, [77], pp. 13-14). Hence, "Nature should be viewed as unconditioned" (ibid. [78], p. 14). While the mechanical philosophy had long regarded Nature as the product of "dead mechanism", by thinking of Nature as unconditioned originary activity, Schelling could announce two fundamental consequences for the philosophy of nature, namely the autonomy and autarchy of Nature:

> Since Nature gives itself its sphere of activity, no foreign power can interfere with it; all of its laws are immanent, or *Nature is its own legislator* (autonomy of Nature).
> Whatever happens in Nature must also be explained from the active and motive principles which lie in it, or *Nature suffices for itself* (autarchy of Nature).
> They are both contained in the proposition: *Nature has unconditioned reality,* a proposition which is precisely the principle of a philosophy of nature. (ibid. [81], p. 17)

Thus, by rethinking Kant's unconditioned not as the **absolute totality of the series** of conditions **that** one may represent in imagination as grounded in an individual being, but as *being itself* qua originary activity in Nature, Schelling set the philosophy of nature onto a new path . For Nature could now be known not just *formaliter,* as Kant held, that is, according to the connection of the determinations of appearances via the principle of causality. Instead, Nature could now be known also *materialiter*, that is, according to what Kant would have described as the thoroughgoing connection of appearances through an inner principle of causality. Kant's divide between nature and freedom was removed.[5]

Nature is free in its originary activity: it gives laws to itself and it suffices for itself. Nature needs no causes beyond the "active and motive principles" that lie in nature itself, and no laws beyond those immanent in its active and motive principles. These two principles (Nature's autonomy and autarchy)played a methodologically important role in the development of the philosophy of nature in the early nineteenth century. The blossoming of electromagnetism, electrochemistry, and, eventually, thermodynamics in the first half of the nineteenth century, was deeply influenced by this philosophical image of Nature as an originary activity. Nature, in all its forms and interchangeable appearances expresses, the autarchy of its active motive principles according to its own immanent laws, laws which humankind can aim to discover.

While the mechanical philosophers of the previous century lacked the principles that could explain how corpuscles or atoms could be set in motion and compose the variety of forms we observe in nature, Kant's dynamical philosophy remedied this problem by introducing the two fundamental forces of attraction and repulsion in the *Metaphysical Foundations of Natural Science* (and even earlier, in the *Universal Natural History* and *Physical Monadology*). Yet, Kant's philosophy of nature too, in Schelling's view, fell short of providing a comprehensive "construction of matter" out of the two fundamental forces. Moreover, Kant saw the lawfulness of nature as originating from the faculty of understanding and its ability to 'prescribe laws to nature' (see Kant 1781/87/1997, B163–B165). With Schelling, Nature is inherently lawful: its lawfulness is to be found in its active motive principles and the laws it gives to itself. How Schelling saw his enterprise as that of building upon and improving on Kant's construction of matter is the topic of the next Section.

4. Unconditioned Empiricism and actants as natural monads

In the *Metaphysical Foundations of Natural Science*, Kant famously offered a detailed analysis of his construction of matter according to the four main categories (quantity, quality, relation, and modality). Hence, the four chapters of Phoronomy (matter as quantity), Dynamics (matter as quality), Mechanics (matter as relation), and Phenomenology (matter as modality). In the chapter on Dynamics, Kant defined matter as "the *moveable* insofar as it *fills a space*. To *fill* a space is to resist every moveable that strives through its motion to penetrate into a certain space" (Kant 1786/2004, AA4: 496). From this definition, Kant introduced the fundamental force of repulsion to explain how matter can fill a space and hence be impenetrable in purely dynamical terms. And with repulsion posited, he went on to introduce attraction as a force necessary to counterbalance repulsion, which left to itself would result in matter filling up the entire space. The seminal idea of two fundamental forces —counterbalancing each other and explaining how matter fills space dynamically— can already be found in Kant's pre-Critical text *Physical Monadology* (1756/1992). By building on the dynamical metaphysics of his predecessors (from Leibniz to Wolff), Kant's pre-Critical text defines a physical monad as, yes, a monad, in that it is the simplest element of a body. Yet it is also a "physical" monad, capable of filling space not "by the plurality of its substantial parts, but by the sphere of activity, by means of which it hinders the things which are external to it and which are present to it on both sides from drawing any closer to each other" (Kant 1756/1992, AA1: 480).

In *First Outline*, Schelling goes back to Kant and builds on his notion of a physical monad. Indeed, he takes from Kant the idea of "original qualities", which are needed to ground all occupation of space and yet not be themselves in space, for otherwise they would be (like anything else which is in space) "affected by physical force; …mechanically or chemically destructible" (Schelling 1799/2004, [84], p. 20). Schelling identifies the original qualities as "the most originary negative presentations of the unconditioned in Nature". The original actants —as Schelling calls them—are therefore not in space themselves and "they cannot be viewed as part of matter", but are instead "constituent factors of matter" (ibid., [86] pp. 20-21): "For us, every original actant is just like the atom of the corpuscular philosopher; truly *singular,* each is in itself whole and sealed-off, and represents as it were a natural monad" (ibid., [86] p. 21).

Thus Schelling's so-called *dynamic atomism* represents an attempt to go back to the Leibnizian-Wolffian-Baumgartean notion of monads as fundamental simple units. In contrast to Kant's physical monads, natural monads are not themselves in space, that is, filling up space with their sphere of activity (defined by the counterbalance of attractive and repulsive forces). Natural monads are not material (or constitutive of matter). Instead they are actants: they are *action*, whose effects and products are "presentable in space" (ibid., [86] p. 22). At the same time, Schelling's notion of "actants" does not hark back to any *bona fide* Leibnizian monadology. For Schelling clearly says that

> the actant itself, abstracted from its product, is nothing. Indeed, it is nothing other than the product itself viewed from a higher perspective. (…) Our knowledge does not reach *beyond* the product, and no other expression for the magnitude of the action can be given than the *product itself.* The philosophy of nature has nothing further to do than recognise the unconditionally empirical in these actants. Empiricism extended to include unconditionedness is precisely philosophy of nature (ibid. [87], p. 22).

Two points are worth underlining in this passage. First, although originary qualities qua actants are for Schelling's nature's building blocks (hence the name "dynamic atomism"), our knowledge is confined to the *products* of these actants. Indeed, Schelling is even more radical in claiming that the actants are nothing other than the products themselves "viewed from a higher perspective". Thus, far from harking back to Leibniz's monadology, Schelling gives a brand new twist to old philosophical discussions about the boundaries of human knowledge. Human knowledge is confined to the products of the originary qualities, and we can think of the latter only through their products as *viewed from a higher perspective.*

Second, Kant's discussion of the unconditioned, with its sharp distinction between nature and freedom, becomes—in the hands of Schelling—a reflection on the *perspectival* character of human knowledge. For Kant, our knowledge is confined to nature as a series of conditioned items linked according to the principle of causality. By contrast with Kant, Schelling seems to suggest that we can have knowledge of the whole series, .that is, knowledge of the unconditioned, if we look at the very same series of conditioned products "from a higher perspective". Kant's dichotomy of natural causality and freedom gets blurred.

For Schelling, as for the German Idealists after him, the unconditioned manifests itself in nature —indeed, it is present in nature via the empirical products of its originary activity. Kant's "empirically unconditioned" qua "**intelligible** condition," which does not belong to the series of appearances as a member (see Section 3 above), has become Schelling's "unconditionally empirical" in the actants: the distinctive object of Schelling's philosophy of nature. Thus, in a way, traditional criticisms of Schelling's *Naturphilosophie* as being too speculative and remote from experience and experiments, seem to miss the point. For it is not as if Schelling's speculative philosophy of nature is designed and intended to eschew empiricism. On the contrary, Schelling's speculative philosophy of nature is meant to extend empiricism to include unconditionedness —no doubt, an unpalatable result in Kantian and neo-Kantian quarters.

But, more to the point for the rest of this chapter, it is precisely by this move of making the actants known through their products (when viewed from a higher perspective), and of thereby extending empiricism to include the unconditioned, that some intriguing points of contact between Schelling's *Naturphilosophie* and the sciences of the time begin to appear. In a footnote attached to the long passage quoted above, Schelling made the move explicitly. For he complained that Kant nowhere ventured into explaining the specific diversity of matter out of his two forces of attraction and repulsion, and others after him (such as Eschenmayer) tried to succeed where Kant failed, without much success themselves (and indeed at the cost of attempting to derive magnetic phenomena a priori, see Schelling, ibid., footnote p. 22).

Thus, it is the job of dynamic philosophy, as Schelling portrays it, to explain the ultimate construction of matter out of these two fundamental forces. More precisely, it is the job of Schelling's *Naturphilosophie* to explain how from the original qualities or actants (attraction and repulsion) very many different effects can result——from electrical phenomena, to mechanical phenomena, down to what Schelling describes as the "lowest level of their appearances (in the chemical process)", that is, how alterations of "cohesive force, of density, of specific gravity" can all be regarded as alterations of these two basic forces (ibid., footnote, p. 23). Moreover, explaining all these effects from the original qualities or actants does not necessarily imply rejecting "particular materials for the explanation of natural appearances", such as "the materiality of light or the existence of galvanic fluid", for "one cannot get off the hook so easily", Schelling warns (ibid., footnote p. 22). How can Schelling's *Naturphilosophie* provide an explanation for all these natural phenomena out of the original qualities qua actants? What does Schelling have to say about heat, electricity, and chemical reactions, for example? We answer these questions in the next Section.

5. Schelling on heat-matter, electricity, and oxygen

Let us then take a quick look at Schelling's bold and speculative reflections on the physical sciences of his time. The purpose of this brief exposition is to highlight three key aspects that betray his wider engagement with the sciences of his time and the burgeoning field of electrochemistry.

In open polemic against the atomists and the mechanical philosophers, Schelling defended a picture of nature in which the original actants are nowhere to be found but they are acting all the time to produce the variety of forms and products we see in nature, "from the crystal to the leaf, and from the leaf to human nature" (Schelling 1799/2004, [90], p. 26). Schelling identified the original formless principle present in the variety of forms to be found in nature as a fluid, or better "the most original fluidity": the "*principle of heat*, which is, consequently, no simple substance, no material at all, but always only the phenomenon of constantly diminished capacity (of original actants for one another) and is therefore proof of the steadily enduring process of organisation in Nature. New theory of heat according to these basic principles" (ibid., [91], pp. 27-8).

This primordial, original fluidity is nothing other than "fire or heat-matter" and is said to "*reveal its existence in no other way than through decomposition*" (ibid., [93], p. 29). Fire is said to be *simple* because "no duality has yet been perceived in it, or a decomposition in opposed actants, as with e.g. electricity" (ibid., [94], p. 30). It goes without saying that Schelling was here endorsing a deeply entrenched view at the time of heat as a fluid matter, pervading all bodies and at work in the transitions of physical states. Kant himself had advocated this view in his 1755 *On Fire*, following an influential tradition of Newtonian speculative experimentalism that goes back to the Queries of Newton's *Opticks*, where an ethereal matter is hypothesised as the medium of light and heat. This Newtonian tradition was developed further in the early eighteenth century in the

Netherlands, thanks to the Dutch Newtonianism of Herman Boerhaave, who also defended fire as a fluid material substance.[6]

But what is new and interesting in these speculative remarks by Schelling is the opposition he draws between the simple original fluidity of heat and the duplicity typical of "phenomena of electricity (in galvanism and other recently presented experiments)" (ibid., [94], p. 30). Yet, differences aside, heat and electricity are also connected: "since heat as well as electricity is excited through friction …it appears that in every repulsion of different bodies the absolute fluidity which permeates them all —(because it strives to liquefy everything)—is posited, both mechanically from equilibrium and dynamically from their original combination. The former furnishes the phenomenon of heat diffusion. The latter the phenomenon of excited electricity". (ibid., [94], p. 30). In a footnote appended further down to the same passage, Schelling mentions oxygen as "doubtless the single really irreducible element—not as if it were *simple*, but for another reason that will be developed below. But even this material is also the most composable that we are aware of" (ibid., [96], p. 31, footnote). What do heat-matter, electricity, and oxygen have in common? How is the original fluidity of fire related to the duality of electricity, and how is the latter in turn related to oxygen as an irreducible element?

We touch here a central point for my exposition: namely, the two-way street along which the physical sciences of the time (in particular, the burgeoning electrochemistry) informed, and were in turn informed by, Schelling's *Naturphilosophie.* Before I make some concluding remarks about this two-way relation between philosophy and the physical sciences after Kant, we should briefly turn our attention to Schelling's cultural milieu in the Jena of the end of the eighteenth century and take a quick look at some of the main figures in the scientific controversy surrounding the emergence of Lavoisier's new chemistry.

6. Johann Ritter and the role of electrochemical experiments in the Chemical Revolution

Schelling's *First Outline* was written to accompany his lectures on natural philosophy at Jena in 1799. Jena was the hub of post-Kantian philosophy at the time: in 1789 Schiller was appointed Professor of History, and in 1794 Fichte arrived as Professor of Philosophy. The Natural History Society (*Naturforschende Gesellschaft*) had been established in Jena in 1793, and soon Goethe became its Director. In Jena, Alexander von Humboldt sought help "from a young student of exceptional talent called J. W. Ritter",[7] who was financially sponsored by Goethe. Ritter was meant to help Humboldt in repeating some of the electrical experiments that were animating the controversy between the Italians Luigi Galvani in Bologna and Alessandro Volta in Milan. The Galvani–Volta controversy concerned the nature of electricity, which Galvani (Professor of Anatomy in Bologna) claimed to have discovered via experiments on frogs, as a new imponderable fluid released from the nerves of the animals. Against Galvani, Volta set out to defend a view of electricity not as an imponderable fluid released by animal tissues, but as the product of the contact between the plates of two different metals.[8]

In 1798, Ritter published a text entitled "Proof that a continuous galvanism accompanies life processes in the animal kingdom". This text was clearly known to Schelling and read in the intellectual circles of the time by up-and-coming scientists such as the Dane Hans Christian Ørsted.[9] In that text, Ritter argued a chain of three different bodies (e.g. nerve, muscle and metal) is necessary in the production of galvanic phenomena. More importantly, Ritter ran a series of experiments that laid the foundations of modern electrochemistry. He assembled a rudimentary ancestor of Volta's pile,and he also made important experiments on the nature of water. Was water an elementary substance? Or was it composed of two gases?Their exact nature was the subject of great controversy at the time.

Ritter devised an experiment with a V-shaped tube filled with sulphuric acid and topped up at each end of the V-shape with water. Each end was then sealed with corks, through which a gold wire ran half-way into the water. Ritter connected the two gold wires to his primitive pile, made of zinc and silver plates. The result was that a gas came up at one end (hydrogen at the zinc pole) and another gas (what we now know to be oxygen) bubbled up at the silver pole. Ritter did not interpret this result as evidence that water must be composed of two gases (decomposed under the action of electricity). Instead he thought that each gas was the *product* of the combination of water qua elementary substance with what he thought were 'positive' and 'negative galvanism'. In particular he thought that oxygen was the product of water plus positive galvanism (silver pole) and hydrogen was the product of water and negative galvanism (zinc pole). In other words, by believing that electricity was an imponderable material fluid (along Galvani's original conception), and that water was itself an elementary substance, it was natural for Ritter to assume that the combination of electricity with water could produce new compounds: namely, the two gases observed at each end of the V-shaped tube.

[10] In a recent book that discusses at length the Chemical Revolution and the role of electrolysis in it, Hasok Chang has noted affinities between Ritter's view and Joseph Priestley's very similar view in England in 1802 (just a few years after Ritter's experiments and after the Voltaic pile in 1800). Priestley was one of the most famous advocates of the old phlogiston theory, which was the received scientific view before Lavoisier's introduction of oxygen and new system of chemistry in 1789. According to phlogiston theory, combustion and calcination phenomena are the product of an imponderable fluid, called phlogiston, being either released or captured by material bodies under the action of fire. We now describe these same phenomena in terms of oxygen chemically combining in compounds (e.g. oxidation). But before Lavoisier's so-called Chemical Revolution, phlogiston provided the received view for explaining these chemical phenomena.

Like Ritter before him, Priestley too in 1802, (possibly unaware of Ritter's similar conclusion published in German just a little earlier) concluded that there is a link between what he called positive electricity (rather than positive galvanism) and dephlogisticated air (or 'air devoid of phlogiston'—what we now identify as oxygen), on the one hand; and between negative electricity (rather than negative galvanism) and what Priestley called phlogiston (rather than hydrogen). Water was regarded as a mixture of two electric fluids (positive and negative), which produce two different kinds of airs. In a period of lively scientific controversies concerning both the exact nature of electricity (i.e. an imponderable fluid hidden in animal tissues vs. a product of metal contacts), *and* the exact nature of chemical elements (i.e. phlogiston vs. oxygen), it is no surprise that the same experimental evidence about electrolysis lent itself to wildly diverging interpretations. Chang describes Priestley as belonging to the family of what he calls the "old phlogistonists", but lists Ritter among the "new anti-Lavoisierians", namely a new category of dissenters "who fully acknowledged that Lavoisier's system had become established but also sensed that its time was passing quickly".[11]

Chang also sees important analogies between Ritter's view about water being an element consisting of positive and negative galvanism and Henry Cavendish's similar view, which identified hydrogen with phlogisticated water, and oxygen with dephlogisticated air. Chang makes a case for what he considers the historical plausibility of Ritter's anti-Lavoisierian "synthesis view" about electrolysis, according to which, at the positive pole of the battery, positive electricity combined with water to form oxygen, and at the other pole, negative electricity combined with water to produce hydrogen.

Chang cites Arrhenius's electrochemistry textbook, which, almost a century after Ritter's original experiments (in 1897) still presented Ritter's view on electrolysis as the "initially predominant view" and "sensible enough at least for its own time".[12] So what was wrong with Ritter's view? And why did not it gain more popularity vis-à-vis Lavoisier's view?

The main objection against the view, according to Chang, arose in 1803 when Berzelius observed how the same phenomenon of the two gases could be produced with substances very different from water, such as sulphate of potash.[13] Yet Chang remarks that even Berzelius' objection was not a knock-down argument against Ritter. It is more likely that Ritter's view became very unpopular because of its association with speculative *Naturphilosophie.* The scientific establishment simply did not know what to do with Ritter's metaphysical speculations and even prophecies. The way Chang describes the misfortunes of Ritter's view is particularly telling:

> Although he was very popular with scientists and philosophers sympathetic to Romantic *Naturphilosophie*, Ritter's standing in science declined as unfavorable reactions to *Naturphilosophie* set in among men of science. Even phlogistonists were on the whole quite sober-minded people who did not like Ritter's wildly brilliant style of science. It is telling that Priestley did not ally himself with Ritter. Ritter's view on the electrolysis of water was thrown out by mainstream science as part of a comprehensive rejection, and layers of it: the rejection of his views on electricity in general, the rejection of any theories of chemistry incorporating elementary water (including the phlogiston theory), and the rejection of *Naturphilosophie* (Chang 2012, p. 94).

Let us concentrate for a moment on the last aspect of this thoroughgoing rejection of Ritter's view among the scientists of his time. Was Ritter an outcast because of his connection with the dubious claims of Schelling's *Naturphilosophie*? The relation between Ritter and Schelling's *Naturphilosophie* has been, and continues to be, a matter of controversy and debate. Christensen, in the latest scientific biography of Ørsted, is adamant in drawing a line between Schelling's controversial and speculative philosophy of nature and Ritter's brilliant experiments.[14] Christensen makes some remarks that seem to support Chang's conclusion about Schelling's bad reputation in his own cultural milieu at the time. For example, Christensen observes how Schelling's own journal *Zeitschrift für speculative Physik* became the official venue for publicizing Schelling's own bold and unscientific ideas, the very same ideas that were ostracized in the *Jenaer Allgemeine Literaturzeitung.*[15]

Schelling's student and protégé, Steffens, "was burdened with the accusation of being the smart disciple of a charlatan"[16] and denied a University post. What is worse, even Schlegel and Novalis, friends of Ritter, "detested Schelling. They found that he strutted in borrowed plumes when he tried to found his *Naturphilosophie* on Ritter's experiments while not doing any research himself".[17] Yet apparently, according to Christensen's account, both Ørsted and Ritter warmed up to Schelling after 1805.[18]

At the age of 34, in 1810, Ritter died. Twenty years later, Steffens (soon to become Vice-Chancellor at the University of Berlin under the auspices of the new king of Prussia, Friedrich Wilhelm IV) wrote *Polemische Blätter,* in which he himself (*tu quoque!*) repudiated Schelling's *Naturphilosophie* as being remote from empirical research and as sheer speculation.[19] Ørsted, in his "Dialogue on Mysticism", presented at the Scandinavian Literary Society in 1809, left what is probably the most revealing aspect of the Kantian (and anti-Schellingian) methodological legacy for the physical sciences of the nineteenth century. In Christensen's words:

> Following Kant, we cannot have true theoretical knowledge about nature in itself, because nature-in-itself is infinite and can only be fully understood from God's omniscient position, while our intellectual faculty is finite and operating from one particular perspective only. …Ørsted's dialogue is devoid of Schellingian tropes and terminology. There is no world soul, no absolute, no identity, no potencies or indifferences, and no pantheism. …This shows that at an early stage he was more attracted to *Naturphilosophie* than he ended up being. (Christensen 2013, p. 241).

What is to be said about Christensen's judgment on Schelling's *Naturphilosophie*? One thing seems certain. Schelling's speculative philosophy of nature seems to have been shunned even by friends and contemporaries of Schelling, such as Steffens, Novalis, and Schlegel. Schelling's scientific standing (and that of his associates, from Steffens to Ritter) was also discredited by the scientific establishment of the time. And Schelling's philosophical legacy for the physical sciences of the nineteenth century was overshadowed by Kant. If socio-political considerations are allowed to play a role in the final historical appraisal of any intellectual figure, Schelling's case constitutes, to my mind, a perfect case in point (whatever one might think about Schelling's philosophical merits). In the next and final Section, I make some concluding observations on Schelling's troubled legacy for the physical sciences of the nineteenth century by going back to his remarks on electrochemistry in the *First Outline*.

7. Schelling's controversial legacy for the physical sciences of the nineteenth century

What was the value of Schelling's *Naturphilosophie* for the physical sciences of the time? Let us resume our brief exposition of Schelling's ideas about heat, electricity, and oxygen and draw some conclusions in light of the *cultural milieu* of the time. In the Second Division of the *First Outline*, Schelling makes some bizarre remarks in the context of an even more bizarre claim, namely that *light is the phenomenon of chemical action of the Sun on the Earth*.[20] Schelling declares that "if oxygen has the positive role in all chemical processes, then bodies which are related to *oxygen negatively* must also be related to the luminous power of the Sun *negatively*." But what are the bodies that are related to *oxygen negatively?* Schelling's answer is "phlogistical bodies": every true process of combustion, according to Schelling, is nothing but an *absolute opposition* between uncombusted (phlogistical) bodies and oxygen, which relates to phlogistical bodies in a positive way.[21] This language of "absolute opposition", "positive", and "negative" is interesting because it reveals how Schelling patterned chemical processes of combustion on the model of electrical phenomena, where it is the opposition between a positive and negative pole that causes the release of electricity (or what Ritter called positive and negative galvanism).[22] Moreover, it reveals, in the language of "phlogistical bodies", the persistence of the old (pre-Lavoisier) phlogiston theory side-by-side with Lavoisier's neologism "oxygen", which is an alternative principle of combustion (against the phlogiston theory).

But Schelling's ambiguous language (as is to be expected in a period of revolutionary shift) should not confuse the reader. For Schelling is clearly taking a stance here in favor of Lavoisier's notion of oxygen, as a simple substance, which defines and determines all the "negative and positive relationships of bodies AMONG ONE ANOTHER".[23] In the Remark appended to this passage, Schelling qualifies oxygen as "the determinant of quality in the chemical process of the Earth" such that "the electricity of bodies is determined through their relation to oxygen". In other words, "in the ELECTRICAL process that body which is positive adopts *the function* that *oxygen had in the* PROCESS OF COMBUSTION".[24] When we consider two electrical conductors "the one takes over the function of oxygen which has most affinity with it".[25] And in the footnote appended to the passage, Schelling refers to Ritter as the person who "has followed farthest (of all who have noted it) the opposite relation of bodies in galvanism (determined by its opposite relation to oxygen). …*Fluids* which contain *oxidizable components*, e.g. alkaline salts…, are positive in galvanism with solid oxidizable bodies, which are simultaneously conductors of electricity, e.g. all metals. *Fluids,* which are already *oxidized*, like water and other, are negative with the same solid bodies…The illusion resolves itself when one assumes all isolators as such are substances which are *combusted*, not indeed absolutely, but still *relatively*, in relation to the bodies that are conductors of electricity".[26]

Obscure, wrong-headed, and confusing as Schelling's narrative inevitably is, it reveals to my mind an important point: namely that the duality at play in electrical phenomena (between positive and negative poles using the Voltaic pile; or positive and negative galvanism, to stick to Galvani's terminology) is akin to the duality Schelling saw at play in combustion, where oxygen was said to determine the difference between bodies that have already been oxidized and those that have not.

More to the point, Schelling's text, written in 1799 for his Jena lectures, is a treasure trove of information concerning one of the most important scientific controversies of the time concerning the nature of water. In contrast to Ritter, who regarded oxygen as the *product* of positive galvanism and water qua elementary substance, Schelling seems to be taking on board Lavoisier's notion of oxygen as a simple substance. And chemical reactions are defined with respect to the role and function that oxygen plays in them. But there is more. Even electrical phenomena are patterned on the model of chemical phenomena as defined by the function of oxygen vis-à-vis other bodies. The speculative, obscure Schelling was clearly taking a stance in favor of the new Lavoisierians in recognising the central role of oxygen in defining the phenomena of combustion[27]—despite the remnant traces of phlogiston theory, galvanism, and imponderable fluids, in which he decked out his chemical speculations about oxygen.[28]

It is then sadly ironic that Schelling's philosophy of nature was ostracized by the scientific establishment of the time, whereas views that to our contemporary eyes might appear even more bizarre — such as Ritter's notion of water as an element and galvanism as an imponderable fluid — enjoyed a good reputation among his contemporaries (from Humboldt to Goethe and Ørsted). Chang might be right in observing that Ritter's standing in science declined because of the unfavorable reactions to *Naturphilosophie* at the time. But what remains to be explained, in my view, are the exact (socio-political-philosophical) reasons why Schelling's *Naturphilosophie* became the target of such unfavourable reactions in the intellectual community of the time.

Was Schelling's *Naturphilosophie* too aprioristic? It certainly was; but Kant's construction of nature in the *Metaphysical Foundations* was not better supported by experimental evidence than was Schelling's *First Outline*. Nonetheless, Kant's *Metaphysical Foundations* did not suffer the same philosophical misfortunes. Was Schelling's philosophy of nature too speculative? Surely, it was speculative. But no more than a long and venerable tradition of Newtonian speculative experimentalism that had thrived in the Continent and in England throughout the eighteenth century (from Newton's Queries of the *Optiks*, to the work of the Dutchman Boerhaave and the Englishman Stephen Hales). Being 'speculative' in the eighteenth-century natural philosophy was not synonymous with being 'disreputable'. It simply meant the opposite of being mathematically demonstrable—the sort of things Newton would put in the Queries of the *Opticks* (about the ether as a medium for optical and electrical phenomena). Was Schelling's philosophy of nature plainly false and obscure? Yes; but once again, no more than Ritter's prophecies concerning divinatory rods; or Cavendish's language of 'dephlogisticated air'; or Galvani's discussion of animal fluids. Once put in its historical context, Schelling's *Naturphilosophie* does not seem to stand out as more outlandish than many other views of the time. How then explain the harsh historical judgment concerning Schelling?

I can only venture some conjectural remarks on this point. I suspect that to some extent this harsh historical judgment might be due to a combination of academic politics about *who* was the legitimate successor of Kant's philosophy of nature in the Germany of the time, and possibly some anti-French, anti-Lavoisierian trends in the Jena of the turn of the century (which might also explain why Schelling's defense of oxygen has not received more attention even among careful historians of science). Ritter is relatively well-known among historians of science working on the Chemical Revolution, but Schelling hardly gets any mention. Another possible explanation is that by placing the notion of Unconditioned Empiricism center stage, Schelling opened the door for Hegel's Idealism. And most of the scientific philosophy of the nineteenth century has been read through the anti-Idealistic lenses of either Marburg's neo-Kantianism or the logical empiricism of the Vienna Circle. In this context Idealism appears to have been more important as a catalyst to the eventual achievement of knowledge than as a scientific success itself. The exact nature of this catalytic role is nonetheless worth understanding properly, so that the true merits and limits of *Naturphilosophie* can be recognized.

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[1] For the influence of *Naturphilosophie* on physics, see Gower (1973). Pearce Williams (1973) has been an advocate of the interpretive line that traces back to Schelling's *Naturphilosophie* the Dane H.C. Ørsted's discovery that the passage of electric current in a wire twists sideways the magnetic needle of a compass. Pearce Williams also extended the influence of *Naturphilosophie* to Faraday's discovery of electromagnetic induction, via Humphry Davy, Director of the Royal Institute where Faraday started his career as a bookbinder (and via the poet Samuel Coleridge, who was in turn a friend of Davy and familiar with Schelling). Against this interpretation, Shanahan (1989) has argued that Ørsted owed much more to Kant than to *Naturphilosophie*, having written his doctoral dissertation on Kant's *Metaphysical Foundations*. On the topic, see also Caneva (1997) and more recently, Friedman (2006) and (2013).

[2] See Christensen's (2013, p. 670, ft 15) judgment on Schelling, "whose views were unsubstantiated by experiments".

[3] Volta's invention of the pile in 1800 terminated a long debate with Galvani on the nature of animal electricity, and shed light on the connection between electricity and chemistry that had been at the center of debates surrounding Lavoisier's new chemistry (against the old phlogiston theory).

[4] See Massimi (forthcoming) for a detailed analysis of Kant's view of the causality at play in laws of nature in terms of grounds and determinations, where grounds can be understood as real grounds or <*rationes fiendi*> for the determinations of empirical effects.

[5] For Schelling's idealistic take on the Kantian notions of self and freedom, and for a slightly different analysis of the origin of Schelling's ideas from Kant's third Critique, see Zanetti (1995).

[6] For more details on Kant's view on fire in this pre-Critical text and the wider cultural context of Newtonian speculative experimentalism (inc. Boerhaave) in the first half of the eighteenth century, see Massimi (2011).

[7] Christensen (2013), p. 81, on which I draw here below.

[8] See Pera and Mandelbaum (1992) for details of this story.

[9] See Christensen (2013), p. 82.

[10] Chang (2012), ch. 2, pp. 80-81

[11] Ibid., p. 32.

[12] Ibid., p. 79

[13] Ibid., p. 91

[14] See footnote 2 above

[15] Christensen (2013), p. 168.

[16] Ibid.

[17] Ibid., p. 243.

[18] Ibid., p. 243.

[19] Ibid., p. 549.

[20] Schelling 1799/2004, [163], p. 98.

[21] Ibid. [164], p. 99.

[22] And in the notes appended to the text (notes that come from a manuscript of Schelling's Jena lectures published as footnotes in the *Sämmtliche Werke* edition of Schelling's work, and from there into the 2004 English edition), Schelling mentions Volta's experiments on electricity as follows: "Volta found that by the mere contact of *two* such bodies which act in the electrical process, electricity can be produced that always has + electricity related to oxygen, the other - electricity" (Schelling 1799/2004, [167], p. 102, footnote)

[23] Ibid., 1799/2004, [165], p. 100.

[24] Ibid., 1799/2004, [165], p. 101.

[25] Ibid., 1799/2004, [167], p. 102.

[26] Ibid., 1799/2004, [167], p. 102.

[27] "Oxygen is for us irreducible, and only insofar as it is so can it be the mediating factor of all chemical affinities of the Earth and *limit* the chemical process of the Earth….Oxygen is *by these means* opposed to all other substances of the Earth; that is, all others combust *with* oxygen, while it burns with no other substance." Schelling 1799/2004, [160], p. 95. And in the footnote to the same page, Schelling adds: "A body is combustible to us when it gives off light through disintegration by oxygen…Oxygen is the principle of combustion because no other material stands above it".

[28] Friedman also (2013, p. 79) acknowledges the fruitful role that Schelling's speculative physics played for "the experimental and theoretical work of the principal founders of electro-chemistry and electro-magnetism", despite the negative judgment by Helmholtz who saw in Schelling's *Naturphilosophie* the origin of a "deplorable climate of enmity and mutual distrust" between natural science and philosophy (ibid., p. 80).