“Anschauung” versus Mathematical Insight: Ørsted on Quantification and Mathematical Representation in Natural Philosophy

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Ørsted and mathematics sound like two opposite poles. It is well known that Hans Christian Ørsted (1777–1851) only rarely made use of mathematical tools in his scientific works and that it was a deliberate choice from his side (see for example Pedersen, 1987, pp. 140–149, 1988, pp. 154–162, Meyer, 1920, pp. clv–clxii). The question about a mathematical versus a more immediate, intuitive insight into natural phenomena was important to him, especially as he favoured the latter and felt it needed explanation and defending. In the following I will present Ørsted’s views on scientific method and in particular the role Ørsted attributed to mathematical representation and quantification in natural philosophy. I will suggest historical factors that explain his views and describe how it affected his own research and teaching in practice.

Introduction

In the history of romantic science it is often stated that *Naturphilosophie* and Romanticism was directly opposed to a mechanical and mathematical description of nature, the very characteristics of mainstream French science around the turn of the 18th century. Instead Romanticism implied qualitative, experimental as well as speculative, inquiries of nature in the context of a dynamic and organic worldview (Caneva, 1975, 1993, pp. 282–283, Mullen, 1977, p. 381, Löw, 1979, pp. 294–295, Nielsen, 1989).

Ørsted is often portrayed as the archetype of a romantic scientist and is among the most famous of them. His discovery of electromagnetism in 1820 is one of the most fruitful scientific products of romantic science. This makes it relevant to glance over his views on scientific method. During his whole life Ørsted was quite concerned about promoting his own scientific method as an alternative to the abstract, mathematical approach as well as to the purely empirical data collection.

So the question is what was his alternative method of inquiry? How does his characteristic approach manifest itself in his works in different areas such as in his textbooks on mechanics, his research papers on his chemical system, and in his experimental reports? Why was he reluctant towards mathematical representation? Some of the answers might be suggested already; as soon as we have classified Ørsted as a typical romantic, this is more or less the same as saying that he refrained from the use of mathematical representation.

Ørsted’s views on applied mathematics

Ørsted’s view on the role of mathematics and quantification was not altered much throughout his career.

A theory is an interpretation, a spiritual view of the rational connection of things. Only *he* who finds the way to the spirit through the letter is in possession of a theory" (Ørsted 1852, p. 104–105).

In this quote Ørsted attributes no role to mathematical description in a theory, or at least he rejects that theory can consist of mathematical description alone. On the contrary, the only access to real theoretical insight goes through "the letter" not through mathematical laws.

Ørsted had absolutely nothing against mathematics as such, and he would even admit to the fact that "[m]athematics plays an important role in the presentation of natural philosophy [Naturlærens Foredrag]." It was in the nature of tings that "[e]very change has its magnitude, and so does each of its parts. These magnitudes, as well as the way in which they follow one another, can be determined only with the aid of mathematics." Mathematics "presents the natural laws of magnitudes," natural philosophy "the laws of objects which have magnitude […] Consequently one has always served the development of the other" (Ørsted, 1811(1998), pp. 296–297). "It is highly important for natural philosophy [Physiken] that its truths are also represented in the form of mathematics"(Ørsted, 1847, p. 1458).[1] Ørsted paralleled "[a]pplied mathematics and natural philosophy," because both "deal with the same objects and also share the desire to display the rational connection between the same objects" (Ørsted, 1811(1998), p. 296). However, applied mathematics also had its clear drawbacks:

Many of the very best students of natural philosophy have tried far too hard to impress upon it the form of mathematics, or rather that of Euclidean geometry, whereby it has come to be regarded as applied mathematics. In this way, science is deprived of its natural form. The mathematician tries to deduce all his theorems from the least possible number of simple basic truths. All other considerations are sacrificed for the ingenious stringency of the proofs (Ørsted, 1811(1998), p. 296).

Whereas "[t]he student of nature [Naturgrandskeren] […] endeavours primarily to find the most immediate connection between the effects of the various natural forces," and "often deduces theorems directly from the nature of an effect, […] the mathematician only arrives at them circuitously from some basic truth on which he prefers to build" and is "content with an artificial connection." The student of nature gets some immediate, but fundamental experience with nature "which the mathematician may only borrow" (*ibid.*, p. 197). Ørsted believed that immediate insight [Anschauung] about the true fundamental principles of nature was possible through an inner sense, an intellectual intuition [Indbildningskraften]. By means of *Anschaulichkeit* natural phenomena could reappear in thought or spirit (Ørsted, 1831, col. 855, 1847, p. 1458).

If the natural philosopher merely leaned on mathematical proofs he would loose his freedom of spirit [Aandsfrihed], which Ørsted considered so important in scrutinising the truth of nature (Ørsted, 1805, pp. 92–93). Through "the right study of science" he wanted to "promote the dissemination of spirit" and fight "the ugly application of those abstract axioms, which could easily lead to dangerous consequences from an in itself correct starting point" (quoted from Meyer, 1920,

[1] det er høist vigtigt for Physiken, at dens Sandheder ogsaa fremstilles i Mathematikens Form

p. clxiii).[2] ”[N]atural philosophy [Physics] must be presented and taught [foredrages] in a distinctive [eiendommelig] way based on its nature” (quoted from Meyer, 1920, p. clxii, see also Ørsted, 1831, col. 856, 1847, p. 1458).[3] Thus, Ørsted spoke of ”the theory of capillary action in its *easiest and most appropriate form* of natural philosophy,” which was definitely *not* Laplace's "great mathematical work of art" (Meyer, ed., II, p. 444, Ørsted, 1831, col. 857).[4]

Generally Ørsted wanted to express natural phenomena qualitatively as an alternative to hard-core mathematical theories. It was a matter of principle; Ørsted insisted on a parallel qualitative description of every mathematical, although he had to admit to the fact that certain mechanical phenomena, such as the law of universal attraction, were not describable without the "higher mathematics" (Ørsted, 1809, pp. 102, 104, 195, Ørsted, 1839, p. 55).

This qualitative, *anschaulich* method seems to have worked well for Ørsted himself! Didn't he discover electromagnetism by means of this method? Ørsted definitely acquired greater insight into natural phenomena through speculation and experimental investigation than by mathematical descriptions. Late in life when he had obtained important scientific results by means of his qualitative speculations and experiments, he could therefore only encourage students to follow the same path. He in fact encouraged students to supply their study of natural philosophy by mathematics courses, but he would and could not advice anyone to first become a mathematician before entering the field of natural philosophy (Ørsted, 1847, p. 1458). In his argumentation against teaching the mathematical method, Ørsted stressed that this would lead those students who did not ”possess a distinguished [udmærket] sense of nature,” to focus on ”plurality” rather than unity. It would not lead the students to see the harmony in things (Meyer, 1920, p. clxii).

He further believed that if the method of natural philosophy was the experimental (whether "material" or in thought) then the consequence must also be a revision of textbooks. It was important that the very essences of things, *i.e.*, their effects or active properties, were generated and described in the presentation of natural philosophy. If mathematics was capable of that, then fine with Ørsted; if not, then such mathematical proofs in which in a way activities and effects were hidden should be removed from natural philosophy. It was essential that natural philosophy presented things in their existence and therefore it was the active properties in things, which should be accentuated in order to help the students to *anschau* natural phenomena (Ørsted, 1831).

Ørsted's research and teaching program

Ørsted divided general natural philosophy into dynamics and mechanics, a reminiscent of Kant's metaphysics of nature. He sometimes called mechanics the mathematical part of natural philosophy (Ørsted to Oehlenschläger 1809, Ørsted, M., 1870, vol. 1, pp. 281–82). Otherwise he would denote mechanics the doctrine of motion and dynamics the doctrine of force (and even

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[2] I den Hensigt at virke for Udbredelsen af den Aand jeg her har skildret, og at bekjempe den uskønnede Anvendelse af hine abstrakte Grundsætninger, som let kunne fra et i sig selv rigtig Udgangspunkt lede til farlige Følger

[3] Physiken maa fremstilles og foredrages paa en I dens Natur begrundet eiendommelig Maade

[4] [Afhandlingens] Hensigt var blot at fremstille Haarrørsvirkningens Theorie i sin letteste og for Naturlæren meest passende Form

"chemistry in the broadest sense of this word"). Dynamics comprised chemistry (in the usual sense of the word) as well as theory of heat, light, galvanism, magnetism, and electricity. Not surprisingly, Ørsted's dynamical system dealt with the same subjects as were treated in the prevailing system of imponderables. It was even quite common to attribute all theories of the internal behaviour of these imponderables to chemistry as Ørsted also did (Heilbron, 1993, pp. 28–29).

The difference between Ørsted's system and that of imponderables lay in the theory of matter. Ørsted, like most romantics, opposed the materialistic, atomistic system on which the theory of imponderables was founded. Instead of having atoms as first causes, Ørsted assumed two fundamental chemical or electrical forces which all dynamical phenomena could in the end be traced back to. He defined forces as active properties. Thus, forces constituted matter, not atoms. His dynamical system was also holistic rather than "atomistic" in the sense that in his dynamical system the whole was more than the sum of its parts that entered the synthesis.

"Chemical mathematics" and "chemical numbers"

Quantification had become still more important in chemistry in particular after Lavoisier's quantitative work involving the balance and the discovery of the quantitative laws of chemical proportions. Guerlac has called the laws of combining proportions and the notion of elementary atomic weights "the most fundamental quantitative concept[s] of chemistry" (Guerlac, 1961).

Meanwhile, the strong influence of Ritter's romantic ideas, Schelling's *Naturphilosophie*, and J. J. Winterl's qualitative chemical speculations on Ørsted's dynamical science resulted in a completely qualitative approach to chemical phenomena with much more emphasis on reactivity than on composition of chemical substances (Jacobsen, 2000). While elaborating on his dynamical system in the first decade or two of the 19th century, Ørsted for a time came to believe that certain chemical phenomena could not be explained in a quantitative way (Jacobsen, 2000, pp. 138ff). In particular Ørsted thought that the content of "electricity" in oxygen, acids, and alkalis could affect the quantitative determinations of these substances in manners unknown. For example:

> *Oxygen gas undeniably owes an essential part of its properties to electricity, so we are forced to assume that it has an electric charge or […] bound electricity […I]f electricity plays an important role for oxygen itself, it must be admitted that a very slight change in its charge (bound electricity) can sufficiently change the force with which it acts to render all our quantitative determinations of oxygen useless* (Ørsted, 1805(1998), p. 176).

This view was also reflected in his lectures. In 1810—1811, for example, he gave a course on "Chemistry and internal changes, which cannot be explained by weight" (Engelstoft, 1810).[5] I believe we have to turn to Schelling in order to trace this idea even if it does not help much in our understanding of it. According to Schelling:

[5] Chemien og de indvortes Forandringer, som ei kan forklares ved Vægt

All quality is electricity, and conversely, *the electricity of a body is also its quality*, (for all difference of quality is equal to difference of electricity, and all [chemical] quality is reducible to electricity) (Schelling, 1799(1867), p. 205).

Schelling claimed that ”(chemical) attraction *among the parts* can be called *qualitative*, since it seems to depend on the qualities of bodies.” This was contrary to the force of universal attraction which ”is everywhere proportional to the *quantity* of matter” and therefore quantitative (Schelling, 1797(1988), p. 149). He defined *quality* as ”*action for which one has no mass as its product*” again contrary to the universal force of attraction which could ”be measured by the compound relationship of the amount of matter and its velocity” (Schelling, 1799(1965), p. 24, 1797(1988), p. 266). Probably due to the fact that chemical theory was not yet ripe for a complete mathematical description, he further suggested that ”one cannot expect to have a look inside this action in order to determine the quantity (the degree) of the action through mathematical formulas for example […] Our knowledge cannot reach that *on the other side of* the products, and for the quantity of action there is no other expression than the *product itself*” (Schelling, 1799(1965), p. 24).[6]

[A couple of paragraphs about Ørsted’s interpretation of the laws of combining proportions, which he called “chemical mathematics” and atomic weights wich Ørsted denoted “chemical numbers”]

The characteristics of Ørsted’s *dynamico-chemical* system were that it was founded on few first principles from which the entire theory could be elaborated (Jacobsen, 2000). It was meant to be applicable to a wide range of dynamical phenomena, chemical as well as electrical, magnetic, *etc.* The framing, deductive structure of the dynamical system was meant to resemble that of Newton’s mechanics. In addition, despite the fact that Ørsted’s dynamical system was totally devoid of any mathematical reflections or representations, he frequently expressed hope that his dynamical system would one day acquire a mathematical description on a par with Newton’s mechanics:

The theory of motion has been almost completely transformed into mathematics. The theory of force awaits the inventive mind which can lead it to the same point, for internal forces manifest themselves only in time and space, and their laws cannot be considered completely known to us until we can show all the concomitant circumstances with their correct magnitude (Ørsted, 1811(1998), p. 296).

(see also Ørsted, 1812(1998), p. 311). Such formalism was never established, but one of Ørsted’s students, the later professor of mathematics Henrik Gerner von Schmidten, gave thought to a mathematical formalism of Ørsted’s chemical forces.

Von Schmidten was quite interested in the application of mathematics in the sciences and while staying in Paris in 1820–1824 he therefore spent some time studying which branches of natural philosophy were most likely to acquire a mathematical foundation (von Schmidten to

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[6] *Die Qualität ist Aktion, für die man kein Mass hat als ihr Product selbst* […] Man kann also nicht erwarten, in das Innere jener Aktion selbst einen Blick thun und die Grösse (den Grad) der Aktion etwa durch mathematische Formeln bestimmen zu können […] Den *jenseits* des Produkts reicht unsere Erkenntniss nicht, und für die Grösse der Aktion kann es keinen andern Ausdruck geben als das *Produkt selbst.*

Ørsted, September 1820, Ørsted, M., 1870, pp. 9-10).[7] Apparently he and Ørsted had discussed the possibility of mathematisation of Ørsted's dynamical system, but von Schmidten wrote to Ørsted about his conclusion in this matter in 1820:

I think that if one will hope to give the chemical actions a mathematical theory, which after all is the final and necessary step to perfection of science, one must assume the so-called atomistic theory, but only in the way differentials are considered in the differential calculus, [*i.e.*], without attributing to these any fixed value and to consider their relationship only (von Schmidten to Ørsted, September 1820, *ibid.*, pp. 9-10).[8]

and again in March 1822:

[...] no doubt it is much easier to calculate mathematically the motion of molecules than the oscillations of a fluid [Fluidum], or which is much more likely and philosophical, but unfortunately more difficult, the theory proposed by you (von Schmidten to Ørsted, March 1822, ibid., p. 23).[9]

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[7] Von Schmidten was otherwise clearly inspired by Ørsted's romantic worldview. He wrote an essay on the essence of mathematics and its relation to the other sciences, which was dedicated to Ørsted (von Schmidten, 1827). Von Schmidten set out to explain the epistemology of mathematics and what mathematics *is*. He further wanted to place mathematics in connection with central disciplines of the Romantic Movement: the natural sciences and art. In order to do so he used the conceptual framework of *Naturphilosophie*. He concluded that mathematics ought to be comprehended as an organism, a whole, and he used such concepts as opposites in the function of a line, and that the function expresses the unity of the multiplicity of quantities. He further suggested that mathematical functions showed a dialectical behaviour of polar phenomena like the following phenomena: ”An increase of an item in a machine, of a force in the beautiful or of a certain effort in actions [Handlinger], would reduce the action and could like all exaggeration even lead to the opposite, from the sublime to the ridiculous, from the beautiful to the hideous, from good to evil’ (*ibid.*, p. 5).[7] Similar to Ørsted's definition of a real science (see Ørsted, ??, Jacobsen, 2000, pp. 132–135), von Schmidten argued that arithmetic is not only the science about mathematical quantities, but also the doctrine of functions since ”no mediate [middelbar] knowledge of quantities is possible without the laws of their combinations’ (von Schmidten, 1827, p. 25). Finally, von Schmidten argued that in order to be a skilled mathematician Euclidean strictness was not enough. Rather one must be gifted with an intuitive understanding of the subject, which ”can be assumed to be no less accidental than the one by which quantities in a piece of tones [Tonestrykke] are joined in a beautiful whole’ (*ibid.*, p. 27).[7]

[8] jeg troer, at hvis man vil haabe at give de chemiske Virkninger en mathematisk Theorie, hvilket dog er det sidste og nødvendige Skridt til Videnskabens Fuldkommenhed, maa man gaae ud fra den saakaldte atomistiske Theorie, men blot saaledes som man i Differentialregningen betragter Differentialer, uden at tillægge disse nogen bestemt Værdi, og ikkun betragte deres Forhold

[9] (...det er uden Tvivl meget lettere at beregne mathematisk Molekylernes Bevægelse end Svingninger af et Fluidum, eller hvad der er meget mere sandsynligt og philosophisk, men desværre vanskeligere, den af Dem fremsatte Theorie). Von Schmidten considered the theory of light in terms of double refraction [dobbelte Straalebrækning] and polarity, and the theory of colour in terms of the angle of refraction ready to be mathematised. Perhaps in order to flatter or consolate Ørsted he

Ørsted's qualitative interpretation of mechanics

Ørsted's research was mainly related to his dynamical system within the romantic tradition. Therefore it is ironic that he only completed a textbook in mechanics, which appeared in several revised editions! He never completed textbooks in the subject area of his own research.

Ørsted became professor of natural philosophy [Physik] in 1806 and he then set up a research program in dynamical science and a teaching program involving the two branches of natural philosophy, mechanics and dynamics. He also began writing his own textbooks to support this schema (Jacobsen, 2000, pp. 127–132).[10] In 1809 he published the first volume of a trilogy, a textbook on mechanics or ”the doctrine of motion” which was meant for elementary courses at university and in secondary education.[11]

As mentioned above, Ørsted frequently expressed admiration of Newton's mechanics for its deductive power in terms of few fundamental principles from which everything else in mechanics could be deduced, as well as its clear mathematical representation, and expressed the hope that his own dynamical system would one day find its own mathematiser. However, in his mechanics textbook he in fact deprived this science of its mathematical description. He presented mechanics mainly experimentally based and completely devoid of hard-core mathematics in order to make it more popular and easily understandable.[12]

Olaf Pedersen has documented that this textbook, the following editions, and Ørsted's teaching in mechanics in combination with his great authority in matters of research politics, had a

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suggested that ”these ought to be able to be interpreted [fremstilles] as mathematical results of the fundamental forces of matter' (disse maatte kunne fremstilles som mathematiske Resultater af Materiens Grundkræfter) (von Schmidten to Ørsted, September 1820, *ibid*., pp. 9-10)

[10] Ørsted still in 1844 hoped to complete his textbook trilogy. He published a second edition of his 1809 textbook on mechanics, now called "the mechanical part of natural philosophy," and planned a second volume on heat and light, as well as a third volume on electricity, magnetism, and galvanism. Apart from not mentioning chemical theory the contents Ørsted wanted to deal with had not changed in the last 30 years (Ørsted to Hansteen 1844, Harding, 1920, vol. I, p. 211).

[11] In fact this first volume was finished already in 1807, but the complete impression of the book was destroyed during the English bombardment of Copenhagen the same year (Toftlund Nielsen, 2000, p. 28)

[12] Paradoxically the astronomer and mathematical adept as well as Ørsted's hereditary enemy, Thomas Bugge, criticised this textbook because Ørsted made use of ”higher calculations, differential as well as integral calculus." This is true for Ørsted's treatment of motions caused by a central force, with regard to the universal attraction, swing of the pendulum, and in a few other cases (Ørsted, 1809, §92–§93, §104, §135). Bugge considered this use ”superfluous” because propositions could be illuminated by means of basic mathematics in almost all cases, and ”improper” because it made natural philosophy more incomprehensible and difficult for people not acquainted with infinitisimal calculus (Bugge, vol. 1, 1813, pp. 15–16)!

disastrous outcome for the implementation and dissemination of Newton's mechanics in Denmark throughout the 19th century (Pedersen, 1987, 1988).

[A paragraph will appear here about Ørsted's idea of thought experiments]

The role of geometry and the doctrine of beauty

Ørsted foresaw that the new field of dynamics, *i.e.*, electrochemistry, electromagnetism, *etc*., would soon become a rich field for applied mathematics (Ørsted, 1811(1998), p. 297, 1812(1998), p. 311). Since he found that "[n]atural philosophy has been brought sufficiently close to mathematics, probably even too close," he suggested that "perhaps it is time for mathematics to try to approach natural philosophy" (Ørsted, 1811(1998), p. 297). For this purpose Ørsted chose geometry because of its inner simplicity, perfection, and beauty and made it a topic for intense study for some years around 1807–08. To his friend Oehlenschläger he wrote:

I have found an entirely new way of treating geometry by means of which it unites far more intimately with natural philosophy and in addition becomes far easier to comprehend. It completely transforms into a doctrine of motion (Ørsted to Oehlenschläger, 1807, in Ørsted, M., vol. 1, p. 233).[13]

What Ørsted did was that he proposed to change the presentation of geometry so that "all geometric theorems were presented in a series of thought experiments? In this way, a much clearer and more immediate insight into the real source of every truth would be opened to mathematics itself, and natural philosophy would gain a much more intimate fusion with mathematics than ever before." Ørsted intended to submit his ideas publicly "to the judgment of the experts," but this never happened (Ørsted, 1811(1998), p. 297).[14]

The Danish astronomer, Thomas Bugge, commented on Ørsted's ideas of revising the science of geometry: "It is true that one hears some young and hot heads talking about new methods, new prospects, new views of mathematics,"[15] but Bugge purely rejected this prospect.[16] According to Bugge, geometry would always remain Euclidean (Bugge, 1814, vol. 2, p. vi).

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[13] Jeg har, siden vi saae hinanden, studeret mig mere ind i mathematiken og finder deri guddommelige Ting især i den høiere Mathematik. Lad *Dem* kun foragte den, som burde forstaae den, men ikke gjøre det. Jeg har fundet en ganske ny Maade at behandle Geometrien paa, hvorved den langt inderligen sammenknytter sig med Physiken og tillige vorder langt lettere at fatte. Den forvandler sig ganske til en Bevægelseslære.

[14] He did leave some manuscripts to be found at the Royal Library which, however, I have not yet have the time to study closely.

[15] Vel hører man nogle unge og varme Hoveder at tale om nye Methoder, nye Udsigter, nye Anskuelser af Mathematik

[16] Hansteen had noticed Bugge's remark: "Jeg kan vel tænke at det ogsaa er Dem han mener med de *unge varme* Hoveder, som have nye Anskuelser i Mathematiken osv. Den gamle giftige Knegt vilde saa gierne give Dem et Puf, naar han kunde komme til" (Hansteen to Ørsted 1815, Harding, 1920, vol. I, pp. 108–109)

Part of the reason Ørsted picked geometry was its inner beauty. Although Ørsted maintained that more beauty was found in the experimental practice, he clearly recognised the beauty of geometrical figures (Ørsted, 1843(1851), p. 155). He further believed that it was an obligation of natural philosophy to enlighten the connection between the laws of beauty, which appear to us in geometrical figures and those laws of beauty, which appear to us during our endeavour to scrutinise the laws of nature.

Geometry was clearly part of Ørsted's "science of beauty" [det Skjønnes Naturlære], because the laws that produce beautiful mathematical forms were those, which were most easily comprehended, hence the most *anschaulich*. Symmetry implied beauty, lines and figures expressed thoughts. This impression was not generated by the thinking itself, but was combined with the immediate apprehension [umiddelbare Opfatning], *i.e., Anschauung.* The idea of a thing was the unity of thought expressed in it, comprehended by reason, but as spiritual *Anschauung*. Beauty was then the idea expressed in the thing in so far as it appeared to our *Anschauung*. In symmetry the idea's inner harmony appeared to us immediately. Other romantics, for instance Schweigger, favoured geometry for the same reasons (Caneva, 1975, p. 107–109).

Contextualising Ørsted

Ørsted's opinion about mathematics applied in natural philosophy has been regretted by (Danish) historians who suggested that Ørsted could have played a larger role in the development of the theory of electromagnetism (Meyer, 1920). Furthermore, he has been scolded because he did not introduce Newton's mechanics properly at the University of Copenhagen while he had the chance (Pedersen, 1987, 1988). Previously Ørsted's science has mainly been characterised in the context of the "standard narrative" of electromagnetism or of chemistry or of mechanics. Thus his electromagnetic theory, for example, was mainly compared to Ampère's or Faraday's, and it was regretted that he did not grasp the mathematics in Ampère's theory (Meyer, 1920a, p. cviii, 1920, p. clxi, Knudsen, 1987). However, Ørsted's works and style were generally readily accepted in Germany—and not only among the romantics—where the mathematical approach to natural philosophy was not required nor particularly rewarded (Caneva, 1975, p. 27)

Thus, in order to contextualise Ørsted's method it is necessary to turn to Germany. Around the turn of the 18th century there was a genuine hostility or reserve towards the application of mathematics in German natural philosophy,[17] not only among the romantics. It was generally believed that real "physical" understanding was essentially qualitative, expressing *Anschaulichkeit*. It was an implicit attitude that the dominant instrumentalist view in Laplacian science prevented the attainment of knowledge of the true principles of nature. Success of theories was measured on their "physical" content, and as a result of that experiments were also essentially qualitative in nature since obviously numerical data were of little use to a nonquantitative theory! Experiments were meant to demonstrate theory rather than discovering new facts (Heilbron, 1993, pp. 1–3, Caneva, 1975, 1980).

Many of the characteristics of this German group of natural philosophers fit Ørsted's scientific style perfectly. For example, with regard to subjects subordinated his dynamical system

17 Caneva denotes it "concretizing science" (Caneva, 1975).

his experiments were mainly qualitative. This was particularly true for his chemical experiments. He resisted in using mathematics in the belief that mathematics could not capture the true physical structure of reality. According to Caneva, concretising science”was not simply unmathematical, but self-consciously defended an ideal of science which held sophisticated mathematical description in low esteem, because the latter tended to mislead the natural philosopher from his proper field of study.” This attitude, which ”represented a conscious choice between known alternatives,” clearly also characterises Ørsted. Rather he would seek explanations of phenomena (again particularly chemical phenomena) in terms of their location within a larger conceptual schema (see Jacobsen, 2000). Thus ”the explanation of a particular phenomenon was sought in terms of its association with other known phenomena” (Caneva, 1975).

To be sure, many, perhaps all, of the above-mentioned characteristics also figure in romantic science and there even to a greater extent. In addition Ørsted evidently also had a dominant element of aprioristic deduction and reliance upon reason to discover the underlying basic principles of nature, inherent from *Naturphilosophie*. Owing to this influence he was preoccupied with unity, dualism, and polarity in nature and the belief that all knowledge could be synthesised into a harmonious whole. Add to this his opposition against mechanistic or “physical” atomism, *i.e.*, the belief in solid billiard kind atoms as the smallest building blocks of matter (Caneva, 1975). Ørsted looked for the timeless ideal form and he found a central aspect of it when he discovered electromagnetism. He explained this phenomenon by means of a qualitative *anschaulich* theory and then more or less withdraw from this wide, extremely interesting and promissing research area he had opened, only to reappear on the scene when new phenomena, which could be regarded as part of the “ideal form,” were discovered, such as thermoelectricity.

Conclusion

When studying Ørsted, we need to regard him as situated in the periphery of German experimental philosophy as well as Romanticism if we want to understand his qualitative scientific program. Ørsted pursued science according to the method and program of Schelling’s *Naturphilosophie*. This did not imply the same for chemistry or dynamics as it did for the study or communication of mechanics. In chemistry the aim was to provide it with theory, *i.e.*, first of all a theory resting on few fundamental principles from which the rest of the science could be deduced and all chemical phenomena described. It was not the goal of a romantic to provide a mathematical description, but the dynamical system was by no means excluded from having a mathematical model attached to it eventually when theory was ripe and a suitable piece of mathematics had been developed. As this new “kind” of mathematics Ørsted, like other romantics, suggested a new geometrical approach, because this branch of mathematics provided *Anschaulichkeit*, which he thought was required in order represent phenomena in magnetism, electricity, heat, light, *etc*. He was right about the need for new mathematics, only it was not a new kind of geometry, but rather another kind of differential equations.

As for mechanics or the mathematical part of natural philosophy, Ørsted was determined that it should be possible to divorce the mathematical presentation from this discipline. Instead he taught mechanics in a romantic spirit providing it with conceptual descriptions or “thought experiments” and “material experiments.”

Several factors shaped Ørsted's view on applied mathematics. First of all he was as mentioned influenced by Schelling's and Ritter's romantic program in which a more immediate method of inquiry different from the mathematical was announced and practiced. Second, Ørsted subscribed to the German way of practicing experimental philosophy at the time, which was markedly qualitative, even hostile towards mathematical reflections, instead emphasising the aspect of *Anschauung* in experimental results as well as in theory. This suggests that Ørsted's opposition towards applied mathematics was quite deliberate.

Meanhile, there is no denying that Ørsted's views of the application of mathematics was also coloured by his own underdeveloped mathematical skills. One might be tempted to say that Ørsted simply never made it further than elementary geometry in mathematics! It seems he never had an "aha-experience" or "saw the light" by working with the mathematical equations of some physical theory. Rather he saw mathematical representation as an obstacle, which prevented immediate insight into natural phenomena. According to Kirstine Meyer, his lack of mathematical skill also led Ørsted to overestimate his students' difficulty in understanding a mathematical description (Meyer, 1920, p. clxi). Therefore Ørsted actively attempted to popularise as many parts of natural philosophy as possible, which again meant expressing and presenting it in conceptual descriptions rather than in mathematical.

Ørsted was a skilled and ingenious experimenter. His experiments and argumentation related to mechanical problems such as the compression of airs and water, on the measurement of capillarity, *etc.*, were generally quantitative (see for example Jelved *et al*, 1998, p. 597, Knudsen, 2002, Meyer, ed. 1920, vol. III, pp. 367–371). In chemistry, on the other hand, his works, theoretical as well as experimental, were essentially qualitative (Jacobsen, 2000). In his discussion of Ampère's theory of electromagnetism *Anschaulichkeit* was the crux of the matter in his critique of it. Part of the reason for the qualitative nature of Ørsted's arguments and experiments regarding his dynamical system was also that there was no point in making quantitative experiments relating to a purely qualitative theory. To be sure, chemistry in general acquired quantitative status at the time, but Ørsted had difficulty implementing this aspect into his own chemical theory.

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