H. C. Ørsted and Naturphilosophie

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Hans Christian Ørsted was born in 1777 in Rudkøbing. His father, Søren, was the local apothecary. Søren was a busy man with the responsibility for an inn, the local monopoly on the production of alcohol, and a lively business selling medicinal herbs to apothecaries in Copenhagen. Hans Christian and his brother Anders Sandøe were thus sent off to the local German wigmaker and his wife for a rudimentary education. The boys had talent, and other members of the local community were recruited to teach them what they could of languages, mathematics, and the like. The brothers shared their knowledge with one another. In 1794, the brothers began university studies in Copenhagen. At that time neither physics nor chemistry were recognized university subjects.[1] Physics education — such as it was — was handled by the department of pharmacy. The brothers' interests were extremely broad and most certainly included literature, poetry, and philosophy. Their collective imagination was fired by a series of lectures (by Professor Riisbrigh in 1794) on the new philosophical ideas of Immanuel Kant.

Let me offer a quick and crude summary of those aspects of Kant's thinking which will concern us here. In the Critique of Pure Reason, Kant had written that "we know substance in space only through the forces which work in this space, either by drawing others to it (attraction) or by preventing penetration (repulsion and impenetrability); we know no other quality pertaining to the concept of substance in space which we call matter". Having thus eliminated the necessity of matter, which formed the traditional basis of scientific understanding, it was necessary to find a new formulation of science in terms of forces alone.[2] This was the goal of Kant's Metaphysical Foundations of Natural Science (1786) which suggested the form of a new dynamical physics based only upon the existence of fundamental forces of attraction and repulsion. Matter was made subordinate to these forces — "Matter fills space, not by its pure existence, but by its special active force". Since space was continuous, point-like atoms did not and could not exist. Rather, Kant would have us associate attractive and repulsive forces with every point in space; the conflict between these forces then leads to all observable phenomena including those traditionally identified with matter. Different kinds of forces seen in experiments were then two be viewed as different manifestations of the two basic forces — attraction

[1] Ørsted became the first university professor in physics in 1817.

[2] It is perhaps tempting for physicists to dismiss this sort of thing is nonsense. One should not be too hasty. Modern notions of the theory of strong interactions give us the option of regarding protons and neutrons as topological configurations of bosonic fields. The fermionic quantum number normally associated with these point-like particles is then to be identified with the topological charge or winding number of the fields. Given the complete equivalence of, for example, the bosonic sine-Gordon model and the fermioinic massive Thirring model, we recognize that these "atomic" and "dynamistic" views of elementary particles have precisely the same physics content. The choice between models thus becomes one of convenience rather than one of principle.

and repulsion. As a consequence, one should expect that it would be possible to convert one manifestation of the basic forces into another. It is worth noting that these ideas were brought to England by Samuel Taylor Coleridge, who found that Kant opened the possibility of creating a more universal form of science which was broad enough to encompass both God and the material universe.[3]

Ørsted's interest in Kant's new ideas was intense. Indeed, his dissertation was devoted to a rewriting and partial rearrangement of Kant's ideas. The "rewriting" was aimed at bringing Kant to the attention of Danes. The "rearrangement" was in no small part aimed at extending Kant's ideas to a similar a priori formulation of chemistry.[4] It is worth noting that even at this early stage Ørsted did not accept *Naturphilosophie* uncritically. He was disturbed that some writers (e.g., Schelling) did not maintain an adequate distinction between "a priori" and "empirical" theorems and, even worse, that many of the empirical theorems were based on the results of incorrect experiments.

It is natural to ask what led Ørsted to reject the prevalent belief in "atomism" in favor of Kant's dynamism. Of course, one can only speculate. I think one cause can be found in Ørsted's very first piece of scientific work — a prize-winning essay on The Origin and Uses of Amniotic Fluid. In a remarkably well-written document,[5] Ørsted picks his way through a bewildering variety of contradictory "facts" regarding amniotic fluid. It must have been frustrating for a young man about to embark on a career in science to recognize that the experimental results of others could not be accepted as true. How much more satisfying it would be to be able to begin with just a few true statements and simply deduce all the rest without reference to the imperfect experiments of others! The pitfalls of this approach were to become apparent later.

Before continuing, let us take a quick look towards England. God and religion played an important role in the lives of Humphry Davy and Michael Faraday.[6] They were both strongly attracted to Kantian ideas (as expressed by Coleridge) as a means to reconcile their scientific professions with their religious convictions. It is no accident that I mention Faraday in the context of Ørsted. The similarities between the philosophies of these two giants of electromagnetism are striking. Indeed, almost everything to be said here about Ørsted applies with equal validity to Faraday.

It is perhaps worth noting that Faraday, the son of a blacksmith and a country maid and a bookbinder by trade, was necessarily a self-taught scientist. Ørsted, of course, had the benefit of a university education. Still, it is probably fair to say that the rather improvised nature of his early education had left its mark. The notion that the nature of the material universe could be deduced from a handful of general, a priori principles has considerable appeal for the

[3]Since matter no longer existed, there need no longer be a duality of matter and spirit.

[4]This was something which Kant explicitly claimed could not be done.

[5]Ørsted was only 20 at the time.

[6]Faraday was a member of a rather curious sect known as the "Sandemanians". They were generally described as serene, kind, ascetic, and antisocial.

gifted autodidact, who is forced to make progress by sheer intelligence only weakly aided by received wisdom.

Soon after Ørsted completed his University studies (in 1799), he was awarded a legacy for travel to Germany and France. His first goal was Germany, where the new *Naturphilosoph* had access to all of the major figures of the day — including the philosophers Schelling, Fichte, and Schlegel. He met and quickly established an active collaboration with Johann Wilhelm Ritter (who was also an eager Kantian) on a variety of chemical problems associated with galvanism.[7] Keep in mind that the voltaic cell had just been invented by Alessandro Volta (in 1800). Electrical experiments were real at the cutting edge of science! Ørsted also became fascinated by the chemical ideas of the Hungarian chemist Jakob Joseph Winterl.[8] Ørsted had all the conditions required to become a complete *Naturphilosoph*. Nevertheless, his *de facto* position soon began to change. While strong elements of *Naturphilosophie* were to remain with him for the rest of his life, they begin to acquire a very different character. Some drama was evidently required and will soon be provided in large measure.

First, Ørsted left Germany for Paris. Once he had improved his French and recovered from some initial culture shock, he found himself to be in a new atmosphere in which the *a priori* truths of Kantian philosophy carried little weight relative to the realities of careful and reproducible experiment. Two events during this period are of special interest. Napoleon was a great supporter of the natural sciences. He was sufficiently interested in recent developments in electricity that he established an annual prize for significant new scientific contributions in this area. For obvious reasons, Volta was an early recipient.[9] Ørsted got the idea that his collaborator Ritter — who was eternally in debt — would be an excellent candidate for Napoleon's prize on the basis of his invention of the electrical accumulator. Ritter provided written documentation of this work which included a long description of what he considered far more important material. Specifically, he claimed that a needle made half of zinc and half of silver would *also* align itself with the earth's magnetic field. Further, consistent with his Kantian view of the underlying unity of forces, he claimed that the earth had two electric poles in addition to its familiar magnetic poles. He even indicated their locations. Ørsted pushed Ritter's case enthusiastically even though he was unable to reproduce Ritter's results with the zinc/silver needle. He won considerable approval from French scientists for the strength of his advocacy but there was nothing but scorn for the results themselves. Needless to say, Ritter did not win the prize.

During this time, Ørsted undertook a rewriting of some of Winterl's most

[7]Ritter is probably best known as the discoverer of ultraviolet light. Much of his work, however, was fantastic speculation based on shoddy experimental work. He was hardly a good influence for Ørsted!

[8]We will deal more with Winterl below.

[9]Napoleon had invaded Italy. Luigi Galvani was required to swear his allegiance to Napoleon. Upon refusing to do so, he lost his University position. He died soon after. Volta was more pragmatic and agreed to declare his allegiance to Napoleon. This was evidently a wise decision.

exciting ideas. Specifically, Winterl had the notion that there were two physical substances, "andronia" and "thelykke",[10] which were purported to be the underlying causes of all acidity and alkalinity, respectively. Winterl even gave extremely explicit instructions for the production of andronia. Winterl's results really suited Ørsted's Kantian inclinations. While acknowledging that he lacked the opportunity to check these experiments himself, Ørsted provided a thorough summary of Winterl's arguments and established himself as a champion for these new ideas. The resulting book was published in 1803 and was savaged by critics in France, England, and Germany. While Ørsted received some personal praise for providing an exposition far clearer than the original, the results themselves were dismissed as the sheer fantasy which we now know them to be. Ørsted was beginning to acquire an unwelcome reputation as an uncritical enthusiast.

At this time (1804), Ørsted returned to Denmark. A professorship (in the faculty of medicine) was open, and he applied for it. But news of the hostile reception of his writings about Winterl's chemistry traveled fast, and he did not get the position. Ørsted was unquestionably a bright and ambitious young man who had now — at the age of 27 — been burned twice by the advocacy of spurious results. Unless human nature has changed greatly over 200 years, I suspect he would have begun to recognize that it was a wise idea to pay rather more attention to the experimental details and to revise the role which his philosophical convictions played in his scientific activities.

This change is apparent in his next major work on acoustic or Chladni figures.[11] Ørsted began a repetition of these experiments in 1804 using metal plates instead of glass and lycopodium (*heksemel* in Danish) instead of sand. As he wrote to Ritter, lycopodium had the advantage that it could acquire a static charge when shaken. Ørsted expressed the conviction that there was a connection between acoustic and electric effects and that lycopodium would reveal the latter. The evidence suggested that this was indeed the case. After a well-developed acoustic figure had been formed, Ørsted tapped the inverted plate and discovered that a residue of lycopodium adhered along hyperboles (although not along the nodal lines themselves). These conclusions were supported by literally hundreds of careful measurements performed over the following three years.[12]

His experimental results were greeted with international recognition when presented to Videnskabernes Selskab in 1807, published in German in 1809, and finally published in Danish in 1810. He was awarded a silver medal from Videnskabernes Selskab in 1808 and was made a member later that year. He

[10] These are the Greek words for male and female, respectively.

[11] In 1785 E. F. F. Chladni took a violin bow to a square glass plate strewn with sand. The bow could excite acoustic resonances (consistent with the boundary conditions of how he held the plate) and the sand would then be thrown onto the nodal lines of the plate. This work was described in detail in Chladni's *Die Akustik* published in 1802.

[12] These experiments were repeated some 15 years later by both Savart (who made no mention of Ørsted's results and Faraday (who mentions Ørsted in passing). Their results confirmed Ørsted's work in all details.

was also made a corresponding member of the Academy of Sciences in Munich immediately after publication of the German version of his paper. However, his underlying motivation for these studies — the unity of mechanical and electrical phenomena — was largely passed by in silence. Similarly, there was little scientific appreciation of his claims that "beautiful" sounds invariably corresponded to simple and highly symmetric acoustic figures. Ørsted was (and remained) convinced that the untrained esthetic senses responded intuitively to the unseen reason of God — that there was an underlying harmony between the human spirit and the divine laws of rational nature. The negative message of the Ritter and Winterl debacles had now been given positive reenforcement: His professional success depended far more on the quality of his experiments than on the philosophical convictions which led him to these experiments.

Even more reenforcement was soon to come. Ørsted finally sat down to repeat Winterl's experiments and actually make andronia in the laboratory. He followed Winterl's instructions with care but without success. In experiments with impure reagents he *did* find a substance similar to andronia — but closer examination left him with the worrying conviction that it was simply silica. In 1809, when Ørsted wrote his chemical treatise on the Series of Acids and Bases, there are a few general and laudatory remarks regarding Winterl. But all reference to the chimerical andronia and thelykke are gone.

The pattern has now been set for the rest of Ørsted's career. He remained convinced of the fundamental unity of nature as expressed by the existence of two fundamental forces — attraction and repulsion. Since he thus regarded electricity, magnetism, chemical activity, heat, and light all as various manifestations of the same fundamental forces, it was reasonable to seek relations between them. Further, Ørsted believed that even the two fundamental forces should be regarded as merely two manifestations of a single force which he identifies with an all-pervading Divine Reason. (This is not particularly in harmony with Kant.) There is little doubt that these convictions were central to Ørsted and to the grand strategy of his scientific work. Virtually all of the problems on which he now chose to work can be regarded as attempts to reveal these interrelations between manifestations of the fundamental forces or to study the fundamental forces themselves. At the same time, the tactics of his work became increasingly dominated by the demands of careful experiments and reproducible results. His early published work is often characterized by sweeping statements and explicit appeals, for example, to the fundamental unity of the forces. Such statements of a more general character eventually disappeared in favor of the more mechanistic and descriptive style which renders much scientific prose so terribly boring. Ørsted's speculative thoughts were instead relegated to his non-scientific works.[13] For example, the most important conclusion of his work on acoustic figures found its way into Ørsted's *Bidrag til det Skjønnes Naturlære*: Through music and art the reason of God speaks to us even though we are not aware of the fact.

[13]It is worth noting the balance in Ørsted's production. His scientific works are contained in three volumes. His non-scientific works fill nine.

Alfred: Opfatningen af det Skjønne, forsaavidt intet Andet er indblandet deri, foregaar uden nogen Kundskab om Ideen, omendskjøndt den følte Fornøielse udspringer af den hemmelige Overenstemmelse mellem vor sandelige Natur og Fornuften.
Herman: Nu troer jeg at forstaae Dig bedre. Det Skjønne behager os som Indtrykket af en Idee, uden at vi med det samme blive os den bevidste.
Alfred: Det er min Mening ...

This is where acoustic figures play their role. The beauty perceived in the sound is made manifest by the acoustic figure and its "inner mechanism" is thereby revealed:

Alfred: En skjøn Lyd frembringes altsaa kun ved symmetriske Zittringer.
Julius: Det er virkeligt interessant.
Alfred: Det er maaske noget mere.

Let us now jump ahead to 1820. I will not repeat all the familiar stories regarding Ørsted's discovery of electromagnetism. You have heard them before. It is clear that the experiments were performed with great thoroughness and attention to detail. Ørsted was also careful to have these experiments witnessed by gentlemen of high character and reputation in the event that any might doubt his word. The French were sceptical as always but quickly verified all of Ørsted's results.[14] Things went very quickly, and Ampére's law was duly announced in early December of the same year. In March of 1821, Ampére was asked explicitly why this discovery had not been made by French scientists who, after all, had been possession of the necessary equipment for several decades. Ampére's response was revealing: Coulomb had assured his French colleagues that there was no interaction between electric and magnetic fluids. Ørsted was prepared to make his discovery because he was completely convinced that there *must* be an interaction because electricity and magnetism are simply different manifestations of the two fundamental forces.

Given its rare combination of simplicity and profoundity, Ørsted's discovery was instantly acclaimed throughout the scientific world. But there were also grumbles from those who would deny Ørsted priority for his discovery and from those who simply claimed that he had been "lucky".[15] The latter charge particularly stung him, and he immediately responded in print (in an article entitled "Observations on Electro-Magnetism" written in English in 1821). It is to be emphasized here that virtually all contemporary reports[16] describe Ørsted as a man of the utmost decency and modesty. He was not generally given to

[14] The famous Latin article was written on 20 July 1820. By the first Monday in September, Biot and Arago reported their confirmation to the members of the French Physical Society in Paris.

[15] Even Ørsted's friend Hansteen attributed the discovery to luck in a letter written to Faraday.

[16] Including those from Oehlenschläger, Carsten Hauch, and H. C. Andersen.

responding publicly to personal attacks! Ørsted rejected the assertion of being lucky by noting that he had described electricity and magnetism as different manifestations of the two fundamental forces some eight years before. Anyone who has played with the equipment knows that it does not take seven years to discover electromagnetism. Seven minutes is more than enough. Surely, it was fortuitous that Ørsted discovered electromagnetism as he did. What was not at all fortuitous was the grounding in the notions of *Naturphilosophie* which had prepared him for an immediate understanding of the significance of what he had chanced upon.

I would like you to see the quote from Ørsted's 1812 article entitled "View of the Chemical Laws of Nature" which he had in mind. Although the primary aim of this article was to argue for the identity of the chemical and electrical forces, it also contains some more general remarks regarding the two fundamental forces and a statement of Ørsted's objections to atomism. Ørsted wrote:

> An attempt should be made to discover if it is possible to produce some effect on the magnet as a magnet in one of the states in which electricity is found to be extremely bound.

While this statement is quite vague, it is certainly clear enough.

Indeed, this issue of luck continued to bother Ørsted. In 1830 he was the author of an anonymous contribution on thermoelectricity in David Brewster's encyclopedia.[17] In a long introductory section on the history of the subject, Ørsted describes (in the third person) his own discovery of electromagnetism. He refers, again, to the 1812 article but obviously finds himself at a loss to describe precisely what had prepared him for his discovery.[18] After noting his belief in two fundamental forces, he finally settled on the completely neutral explanation: "This was strictly connected with his other ideas".

Let us turn to another major body of experimental which may seem unrelated to Ørsted's philosophical ideas — his measurements of the compressibility of fluids (which started in 1817 and continued for many years). Such measurements are experimentally tricky because the compressibility of liquids (e.g., water) is similar to that of the container in which they are held. As a result, many early measurements were in error. Ørsted was thus forced to devise a "piezometer" which freed his measurements from this crucial source of error. The result, as we might well guess, was that the compression of fluids was found to be directly proportional to the compressing forces. So what? Recall that the Kantian view was to abandon atomism for dynamism — to replace small billiard ball atoms by forces. The naive view of a fluid made of incompressible atoms was that it would be easy to compress until the atoms were close-packed.[19] At

[17] There is no question that the article was written by Ørsted. A handwritten version can be seen in Det Kongelige Bibliotek.

[18] There are several early draft versions in the handwritten text. They are rather detailed and become increasingly clumsy and hard to follow.

[19] The concept of a pressure due to kinetic energy was missing, of course.

that point, the fluid would become completely incompressible. This discontinuous behavior was not at all what Ørsted found: The compression was strictly proportional to the compressing forces. This suggested, for example, that an infinite compressing force would result in a liquid volume of zero! The implication is that the atomic picture fails and only dynamism remains. Ørsted did not say this directly. What he did say was this:

> Da Forfatteren allerede tidligere i adskillige Skrivter har søgt at viise at de elektriske Kræfter ere de samme som de chemiske, kun i en friere Tilstand, og da han tillige har fremsat den Lærre at Magnetismus, Lys og Varme ere Virkninger af samme Kræfter, saa følger deraf, at alt i Physiken, der ei er Bevægelseslære, tilsammen danner een sammenhængende *Kraftlære* eller *Chemie* i Ordets meest udstrakte Betydning.

It is not by accident that Ørsted used the word *Kraftlære*, which is simply a good Danish name for a theory of forces or dynamism. There is no doubt that Ørsted's work on compressibility was filled with beautiful experiments accurately performed with imaginative apparatus.[20] But the purpose of these experiments was to provide experimental evidence in favor of a Kantian dynamism as opposed to the atomic view of nature.

I think it useful to end with another quote from Ørsted's 1812 article "View of the Chemical Laws of Nature". It captures the convictions which shaped his entire career in physics. Ørsted wrote:

> What finally gives the study of nature its ultimate meaning is the clear understanding that natural laws are identical with laws of reason, so they are in their application like thoughts; the totality of the laws of an object, regarded as its essence, is therefore an idea of Nature, and the law or the essence of the universe is the quintessence of all ideas, identical with absolute Reason. And so we see all of nature as the *manifestation* of one infinite force and one infinite reason united, as the *revelation of God*.

It is perhaps fair to say that Ørsted saw his task as that of finding evidence for God in nature with the help of the experimental methods of physics. The scientific evidence is given in his scientific papers. The conclusions are often to be found elsewhere in his literary production. This pattern persisted throughout his life.

Suggested Literature

Ole Bang, "Store Hans Christian", Forlaget Rhodos (Copenhagen) 1986.

There is no serious general biography of H. C. Ørsted. This little book is the best I can suggest. Although it is not a serious scholarly work, there is a wealth

[20] Ørsted's piezometer is still used today in only slightly modified form.

of general information about Ørsted to be found here. The charm of this slim volume is that it was written with evident love and affection. I recommend it strongly.

Rolf Lindborg, "Ånden i Naturen", Gyldendal (Copenhagen) 1999.

This book deals rather explicitly with Ørsted as *Naturphilosoph*. It thus treats many of the issues I have addressed above quite explicitly. There is, in particular, a very readable description of the basic Kantian ideas. In this sense it is to be recommended. Unfortunately, Lindborg knows very little about the physics and chemistry. As a consequence, some care is required of the reader. Even more unfortunate (for me) is the fact that Lindborg writes in a sarcastic manner which simply makes me angry. Nevertheless, this is a useful volume.

Kirstine Meyer, "H. C. Ørsted Naturvidenskabelige Skrifter", Vols. I–III, Andr. Fred. Høst & Søn, (Copenhagen) 1920.

This is the Ørsted bible. Unfortunately, Ørsted's works are presented in the original Danish, German, English, French, and Latin. If you are good at languages, fine. If not, do not try to read Ørsted here. There is a marvelous scientific biography (in English) in Vol. I and an equally fine essay regarding Ørsted's role in Danish society in Vol. III. These essays are well worth reading even if your language skills are not up to the rest.

K. Jelved, A. D. Jackson, and O. Knudsen, "Selected Scientific Works of Hans Christian Ørsted", Princeton University Press (Princeton, New Jersey) 1998.

Here are two-thirds of Ørsted's scientific works including all of the important papers. All are given in English. There is a nice introductory essay by A. D. Wilson which deals with themes related to *Naturphilosophie*. Above all, I recommend reading Ørsted himself. I suggest reading through the introductions and the conclusions — particularly of the earlier works. Ørsted wrote with real style, and we have tried to maintain the sense of his prose in the translations. (Karen Jelved has an incredible sense of language!) After spending some years working with this material, I am profoundly impressed by the intelligence, decency, and humanity of the author. If you read these works and remain unconvinced that Ørsted was a *Naturphilosoph* to the end, I will eat this volume one page at a time.