VI

Kant, Fries, and the Expanding Universe of Science

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The relation between science and philosophy in the first half of the nineteenth century in Germany was characterized by a significant tension: Science became the prevailing signature of culture, and philosophy—at that time dominated by the systems of speculative idealism—lost its authority in matters of scientific rationality. Quite the contrary, philosophy itself became increasingly the target of "scientistic" criticism, that is, it was accused of not (or of no longer) being able to judge what rationality meant in the different discourses of science and of not obeying scientific standards in its *own* discourse (see, for example, Schnädelbach 1983, 88). The growing alienation and even hostility between science and philosophy later in the century led to the formation of a philosophy of science that was relatively isolated from "school philosophy" and was promoted by scientists themselves (as, for example, by Ernst Mach, Hermann von Helmholtz, Ludwig Boltzmann, and Heinrich Hertz).

Jakob Friedrich Fries (1773–1843)[1] was one of the few philosophers and scientists in the first half of the nineteenth century who perceived this development early on and tried to keep philosophy and science together on the basis of a somehow "dynamized" Kantianism. Though the reception of his philosophy of science suffered from unfavorable historiographical, biographical, and political circumstances not to be discussed here (see Pulte 1999a), his approach to the philosophy of science deserves special attention, as it reflects and integrates post-Kantian developments in mathematics and the natural sciences without giving up Kant's principal aim of a transcendental foundation for all scientific knowledge. Fries's commitment to Kant is best summarized at the end of an unpublished letter from 1832:

> Despite all this I remain a Kantian, because in the history of philosophy, what will be estimated more than any of our new findings is Kant's distinction of analytic and synthetic judgments, the fundamental question of how synthetic judgments a priori are possible, the discovery of a transcendental guideline and the system of categories and ideas, the discovery

of pure intuition, and finally the implementation of the doctrines in his critiques.[2]

Kant's transcendental philosophy has been taken as a turning point (not only, but also) in the *history* of the philosophy of science and of the philosophy of nature. As such it serves as an important landmark still in current systematic discussions. The question regarding the significance of Fries's philosophy therefore amounts to a question also about the relevance of all the work that originates in Kant. I propose to deal with his approach as a continuation of Kant's doctrine, which was motivated by the scientific achievements of his time; it can therefore be labeled as a "scientifically adequate" attempt to carry on Kant's approach.

To this end, Fries had to extend Kant's narrow definition of "science proper" as it is highlighted in the introduction to the *Metaphysical Foundations of Natural Science*. Kant's three necessary conditions for "science proper"—mathematicity, apodicticity and sytematicity—are closely related, though not reducible to each other. First, his claim that "in every doctrine of nature only so much science proper can be found as there is mathematics in it" (IV, 470) does not mean, of course, that any use of mathematics within a natural doctrine turns it into science. Second, not any apodictic doctrine is science, as is shown by metaphysics. And third, not any systematically organized doctrine is a proper science for Kant—though it can be science and even "rational science" (IV, 468)—as in the case of chemistry. Rather, proper science, according to Kant, needs a pure part in which the apodictic certainty of its first principles is founded and the possibility of physical objects is guaranteed by a construction of its concept in pure intuition (IV, 469–470). This is the basic idea underlying Kant's concept of "science proper." Its range "shrinks" even further with Kant's elaboration of this concept in the subsequent parts of the *Metaphysical Foundations*. Here it becomes an apodictic and systematic natural science that aims at an explanation of all natural phenomena by the interaction of corporeal masses according to fundamental attractive and repulsive forces. In the end, their mathematical construction is the kind of mathematization of nature that Kant asks for.

Kant's program of the *Metaphysical Foundations* met increasing resistance in the first decades of the nineteenth century.[3] One important reason was that his understanding of "science proper" excluded important new areas of research, especially within chemistry and biology. Even those "new sciences" that made extensive use of mathematics (and in so far followed Kant's ideal) did not reach the type of mathematization Kant was asking for.

And even within Kant's "model sciences," that is, mathematics and mathematical physics, certain developments—such as the rise of algebraic analysis within pure mathematics, of analytical mechanics within mathematical physics, or of the calculus of probability[4]—meant a challenge for those philosophers and scientists who in principle shared Kant's understanding of science.

At first sight, Fries's approach can be characterized as a twofold extension of Kant's strict and rigid understanding of science. First, he develops a *methodology* of science that gives scientific meaning to Kant's synthetic principles a priori in those areas where their constitutive character is by no means obvious. Second, he weakens in an "empiricist" direction Kant's demand that science has to form a *system*, that is, he weakens it in a way that allows the formation of different empirical theories (as sciences) without giving up the idea of a system of all scientific knowledge (as a regulative *ideal*).

This essay aims at a survey of Fries's philosophy of science with special attention to his extension of Kant's understanding of science in relation to scientific development in general. To suit this purpose, details of the history of the different sciences in question are omitted throughout. I first discuss in some detail Fries's "methodological transformation" of Kant's approach. I then illustrate this transformation with some examples from mathematical physics, chemistry and biology. Some concluding remarks on Fries's philosophy of (pure) mathematics are meant to show that it, too, can be characterized by Fries's predominant aim to keep together Kantian philosophy of science and the actual development of science.

From Science to the Sciences: "System" and "Theories" in Fries's Philosophy of Science

Fries devoted a substantial part of his large philosophical oeuvre to methodological and foundational problems of the natural sciences.[5] I will concentrate on one aspect that seems most significant with respect to his extension of Kant's understanding of science, that is, Fries's separation of "theories" from "system" and its attendant methodology.

According to Kant, systematicity is a necessary prerequisite for a body of knowledge to become a science: "Any doctrine, if it is to be a system, that is, a whole of knowledge ordered by principles, is called science" (IV, 467). It is well known that, with respect to natural science, Kant addressed the problem of systematic unity from two different directions. First, he approached it from the "bottom up," where empirical laws are successively brought under more general laws by our reflective judgment and where a logically conceived unity of all laws is presupposed as a regulative ideal of our reason. Second, he considered it from the "top down," where more and more special empirical laws are subsumed under the a priori laws of our understanding as they were "deduced" by Kant in his first *Critique* and specified in the *Metaphysical Foundations* (see, for example, Friedman 1992, 48–49, 242–264). It was shown elsewhere that the first approach is deeply rooted in Kant's precritical physico-theology—Kant himself later refers to a "subjective" and a "formal" teleology (V, 193)[6]—and that it seems philosophically insufficient according to Kant's own standards, in so far as it cannot explain the necessity of the special laws without which they are, for Kant, no proper laws at all but mere Humean regularities (see Pulte 1999b, 306–327): Reflective judgment is not constitutive. The second approach, on the other hand, seems insufficient in so far as it does not show how the great variety of empirical phenomena that refer to different kinds of matter are to be brought under a few very general concepts and laws: Principles of the understanding are not "immediate." Both approaches taken together raise the problem of how they are and how they can be coordinated so as to realize the ideal of a systematic whole of our scientific knowledge.

Fries's Framing of the Argument

Fries comes to this problem at an early stage of his career, and he locates it in one of the most serious defects that he finds in Kant's whole theoretical philosophy: Kant did not separate understanding and reason with sufficient clarity and he therefore mixed up knowledge (by our understanding) and belief (by our reason) at several important points of his transcendental argument. Fries's remedy is to sharply demarcate a so-called "natural world view" of the understanding and an "ideal world view" of reason as two different types of judgment about reality on equal footing (1828–1831, 5:310–324), and to introduce a mediating faculty called *Ahndung* or presentiment.[7] Without going into the subtleties of this modification of Kant's theoretical system (see Elsenhans 1906, 1:335–345), Fries's general argument can be summed up and focused with respect to philosophy of science in three steps.

First, Fries states that Kant's weak demarcation of the faculties of understanding and reason results in a "confusion of theory and idea" (1828–1831, 5:333). A distinction between theory[8] and idea is nevertheless absolutely necessary to circumscribe the legitimate claims of scientific knowledge and separate them from the excessive claims made by the ideal worldview: Science, belonging to the natural world view, emerges in the shape of *theory*. The necessary distinction between theory and idea also implies a demand for the differentiation of two kinds of regulatives that Kant often mixes up: "ideal regulatives" referring to ideas (reason) and "heuristic maxims," referring to theory (understanding) (1828–1831, 5:313ff.).[9]

Second, according to Fries, Kant had declared ideas to be only regulative, but in fact he also used them as constitutive. Fries thereby offers a new interpretation, or rather puts the Kantian notions "constitutive" and "regulative" in concrete terms with respect to philosophy of science. A principle is called constitutive "if, as soon as it is given, it decides the case of its application for itself so that the *subsuming judgment* is able to develop from it science in theoretical form; a principle is called *regulative*, on the other hand, if the *reflecting judgment* has to first seek out for it a case of application and its constitutive purpose" (1828–1831, 5:311). For the present it could be stated that constitutive principles enable theory, while regulative principles enable generalizations. It is important to note that in the case of Fries, as opposed to the case of Kant, this distinction arises relative to particular theories. And even within such particular theories it is not absolute: As we shall see later, regulative principles can become constitutive. According to Fries, Kant did not realize the "potentially" constitutive function of certain regulative principles. By endowing ideas with a regulative function for judgment, Kant implicitly allowed them to function as "physical regulatives" and thus as constitutive of experience, "after he had initially denied them all claims to constitutiveness" (1828–1831, 5:346).

Third, this problem can be removed in light of the first step and the split within Kant's subjective formal teleology, that is, by a distinction between two kinds of regulatives that are not differentiated in Kant's use of ideas: According to Fries, regulatives *of* theories and regulatives *in* theories have to be distinguished. Ideal regulatives contain general definitions about aims and forms of theories and serve mainly to separate theories from ideas; they are not constitutive and cannot become so. Heuristic maxims, however, are regulatives in theories; their function is to subordinate the special (particular empirical facts, particular empirical laws) under the general (particular empirical laws, laws of higher level); they play a leading role for induction. Fries wants to apply his thesis regarding regulative and constitutive principles exclusively to these: Heuristic maxims, that is, maxims of the systematizing understanding, can become constitutive for experience. As he indicates and as will be examined in more detail by an analysis of his understanding of "theory," the heuristic maxims operate on actual given experience, while the ideal regulatives operate on all possible experience—a difference that results from Fries's separation of natural and ideal worldview (1828–1831, 5:332). From the start Fries thus places Kant's problem of coordinating the bottom-up and the top-down approaches in the context of the *natural worldview*, as only in this context it can become a subject for the philosophy of science. The *ideal worldview*, on the other hand, does not refer to a given manifold of experience but to the whole of possible experience, which is not accessible to real science and therefore can have no impact on the philosophy of science.

One System, Various Theories

Kant's subjective formal teleology is "global" in character, that is, it refers to the whole system of nature or the whole system of possible experience. For Fries, this all-embracing notion of "system" can be relevant only to the ideal worldview. However, the relevant "unit of knowledge" for the natural worldview is "theory": "We therefore demand theory in its strictest meaning from the natural world view of things; but just in its opposition to the ideal view" (1828–1831, 5:345). Fries defines theory as "a science in which facts are recognized in their subordination under general laws and their connections are explained by these" (1837, 541). It is crucial in this respect that the unity embodied by a theory can be given neither through experience itself nor through philosophy, because its necessary principles cannot say anything about a particular fact (1837, 551). Theories are characterized rather by mathematical unity. Only pure intuition includes particular facts and general rules, so that only mathematics can contrive the connection of both: "If at all we therefore achieve theory and explanation only through mathematics" (1837, 551).

Fries draws two important conclusions from this: On the one hand, theory can only explain such empirical facts that can be subsumed under the same notions of magnitude (*Größenbegriffe*). On the other hand, it "follows that there should be as many theoretical beginnings in our cognition as there are different qualities. Of these there are, however, various ones in the doctrine of nature [*Naturlehre*], so that any theoretical task in our cognition is limited; the theories of our science cannot be unified in a system, there are instead as many individual theories separated from each other as there are separate qualities" (1837, 552).

This means, in more concrete terms, that different qualities (like sound or heat) can define (at least provisionally) different theories (like acoustics or a theory of heat). However, Fries's "pure doctrine of motion" (*Reine Bewegungslehre*)—an elaboration and extension of Kant's *Metaphysical*

Foundations[10]—retains an exceptional, "towering" role, as its laws are valid for any objects of outward experience, whatever their qualities are; it is the constitutive theory par excellence (1822, 3). But this heritage of Kant's "top down-systematization" is methodologically transformed by Fries in a characteristic manner: As the a priori laws of motion, as given in Fries's phoronomy,[11] are valid for all physical objects, they form what I will later call "a priori anchors" for the development of heuristic maxims of the different theories (such as acoustics, the theory of heat, etc.) in question. As such, however, they do not determine the empirical content of the more special theories, but are to be understood merely as heuristic guides for these theories. Though we shall always try to reduce sensory given qualities to fundamental properties of matter, force, and movement, any actual theory has to accept sensory qualities as given and thus starts its mathematical development with the notions of magnitudes belonging to them: "no outward quality like color, sound, heat, smell etc. can be explained as such, but each alone is the principle of a theory in which the gradual differences are reduced to its most simple relations" (1837, 595, cf. 551–552). Regardless of his general Kantian orientation, Fries here expresses an "empiricist concession" that is rooted in his detailed knowledge of and intimacy with the scientific practice of his time and the differentiation of particular *theoretical* subdisciplines of physics that traditional mechanism could no longer hold together.

We therefore find a pluralism of theories with Fries that clearly goes beyond the scope of Kant's concept of system. This point is decisive for understanding the difference between Kant's subjective formal teleology and Fries's heuristic maxims, because these maxims correspond to concrete theories that need to have a limited range of experience (1828–1831, 5:345). In this sense the maxims always refer to a "really given manifold" (the "reality" of which is the practice of the scientific development of theories) and not to "any somehow imaginable [*irgend zu gebende*] manifold," that is, not on an all-out system of experience inaccessible to science (1828–1831, 5:323).

This restriction of maxims, taken by itself, does not solve Kant's problem, but it points the way to a solution: Kant's problem does not so much reveal a defect of empirical theory building, but rather poses a problem for empirical methodology. Even a theory that has constitutive, that is, mathematical, principles (1837, 551) is in need of such a methodology, because the "deductive range" of such principles is most often limited:[12]

> In each mathematical system we can actually develop the system from the highest principles in forward direction by putting together each complex

> [*Komplexion*] out of its elements; but with these developments we always reach only a certain point where the composition of the complexes will be too large. Here we follow the reverse way of observation, regard the complex as a whole and just try to organize the complexes at large by an involution without completing the evolution down to the last detail. The latter method of induction demands a development of constitutive laws as precisely as possible in order to obtain certain heuristic principles; however, it remains indispensable in its own sphere as all theoretical compositions always treat only general laws without finding the way to a particular story. (1828–1831, 5:312–313)

The experience of incompleteness of each actually performed "development" of a theory expresses the impossibility in principle to complete such a "development," which is a consequence of Fries's restriction to the natural worldview. The quotation reveals, however, that this restriction does not relax the demands on the formation of scientific knowledge, but in a way strengthens them: It is a matter of getting theory and experience into a kind of "dynamical balance" in order to gain (as far as possible) complete scientific explanations—a problem of balancing deduction and induction, constitutive laws and heuristic maxims.

Now, Fries's picture of theory formation is roughly this:[13] Theory starts genetically, as does all our knowledge, with experience and proceeds by means of induction and speculation to general concepts, rules, and classifications, at best up to constitutive principles. This process is not linear: Rules already gained have to be reconsidered in regard to particular cases and serve as guidelines for further generalization on their part. These guidelines therefore have an "anchor point" in prior experience. Speculation provides a second "anchor point," which is a priori: It demonstrates by means of mathematical and philosophical abstraction which general laws are possible at all for a certain field of experience and in what way these laws relate to constitutive theories (that may already exist). For example, in the theory of gravitation experience shows that an attractive and central force between single masses exists, and only experience can find out its degree with respect to mass (empirical fixation); mathematical and metaphysical abstraction, however, define the form of the law of gravitation (a priori fixation; compare 1822, 400–401, 443–499). The guidelines thus "fixed" twice are nothing else than Fries's heuristic maxims, that is, maxims of the systematizing understanding. They regulate the further formation of theory in form of a "rational induction" as opposed to an unguided (in a way "blind") induction. At best, they lead to the discovery of constitutive principles for the theory in question.

This regressive procedure describes only the genetic development up to a constitutive theory. However, the ideal case of such a theory that Fries recognizes in celestial mechanics is the exception (1822, 345). In various fields, for example in natural history, there are theories that he himself—rather misleadingly—describes as "regulative": Their laws are nothing more than generalizations, more or less probable, though it should be noted that even their heuristic maxims have to be directed to the most general constitutive principles of phoronomy (1837, 596). Fries therefore talks about "two different ways" that may serve to develop "theoretical science" (1828–1831, 5:595):

> First we gain *constitutive theories* following the progressive method of the subsuming judgment and then [we gain] regulative theories following the regressive method of the reflecting judgment. In their presentation the constitutive theories proceed systematically from their principles, they therefore demand a principle that allows developments on its own accord, that is, it demands a precisely defined mathematical task. . . . *Regulative theories* first require induction as the method of invention in order to proceed from facts to general laws which here are to be asserted as principles of the theory. (1828–1831, 5:595–596)

These two methods of theory formation—"bottom up" and "top down"—highlight Fries's methodological dissolution of Kant's problem: If (and only if) it succeeds—usually by an interaction of both methods—in reaching a complete constitutive theory, the laws of this theory can be subsumed in a logical, deductive system. Only then does it make sense to talk about the "necessity" of special laws, which was Kant's cardinal problem from his precritical period on (see Pulte 1999b, 314–327). For Fries, however, there is neither a guarantee nor an absolute requirement to demonstrate the necessity of the laws of a theory—no guarantee, as constitutive principles are scarce, and no absolute requirement, as all human science is natural science, and all natural science must be restricted according to the natural worldview: "We presuppose as known that in human convictions this whole [natural] *science must remain separated from the belief in eternal truth*, though it is subordinated to belief" (Fries 1822, 1).

Theory and Unity of Experience

Fries's methodological considerations bring him to another remarkable conclusion: If heuristic maxims as guidelines of rational induction reveal "a priori-anchorage," and if, furthermore, theory in general develops as an interaction of regressive and progressive methods, it is not at all possible to differentiate sharply between the merely regulative and constitutive functions of these maxims: Heuristic maxims of rational induction therefore must have constitutive contents (1828–1831, 5:311).[14] Based on this conclusion, Kant is reproached for "mixing and confusing theory and idea" (1828–1831, 5:333). As Kant does not differentiate clearly enough between natural and ideal worldviews, he consequently makes no difference between heuristic (that is, "systematizing") maxims of the understanding and the regulative ideals of reason, which are both involved in the regulative use of ideas. Though Kant did not want to admit this, the regulative use of ideas goes beyond the mere regulation of experience. As Fries remarks:

> In the most general case this mistake reveals itself in the use of the ideas of soul, the world and the deity, which even Kant falsely recognizes as physical regulatives after he had first denied them any claims to constitutive character. Here he did not understand, however, the nature of the systematizing maxims, otherwise he would have understood that, when applied, each regulative maxim for the natural view of things is only different in degree from the constitutive law and is actually a yet unknown constitutive law at the bottom of the theory.... (1828–1831, 5:346)

By declaring theory to provide the proper unity of experience, Fries of course reinterprets Kant's terms "regulative" and "constitutive": For him, unity of experience proves a meaningful aim only in relation to a certain theory, which means that regulatives as well as constitutives can be specific only to theory. One might call this Fries's principle of localizing by rendering empirical.

With this principle, Fries also intensifies a problem of the philosophy of science—and offers a respectable methodological solution—which remained unsolved with Kant. This is the problem of the relation between the theoretical unification of experience by general laws and the constitution of experience (in the peculiar sense of gaining objective experience of particular facts by science). Kant's claim for a unity of experience without constitution of experience, his subjective formal teleology of the "as if," is hardly satisfactory in this respect. In contrast, Fries's position avoids this kind of teleology and, in a way, appears "modern": Theoretical unification and the constitution of scientific experience are, according to his view, two sides of the same coin.

Kant's Metaphysical Foundations and Fries's Mathematical Philosophy of Nature

The criticism of Kant's philosophy of science that was sketched in the previous section might obscure the fact that Fries's approach is first and foremost aimed at an elaboration and, so to speak, at an "updating" of Kant's *Metaphysical Foundations*. At the same time, Fries sharply rejects the speculative strand of German *Naturphilosophie* as it appears in the works of Fichte, Hegel, and, above all, Schelling.[15] Among Fries's works, his *Mathematical Philosophy of Nature* is most significant in both regards (1822, v–vi, 1–3, 31–32, 397–398, 507–509). It would go beyond the scope of this paper to provide a detailed comparison of the *Mathematical Philosophy of Nature* and the *Metaphysical Foundations*. Instead, I will confine myself to some general observations about several branches of the natural sciences and of mathematics as treated in Fries's work. In this I am guided by two aims: First, I would like to use some examples from the "special" sciences to illustrate and underscore Fries's methodological reflections as presented in the previous section. Second, I will hint at some of the amendations and improvements of the *Metaphysical Foundations* that were offered by Fries and that may be representative of his approach in general. There can be no doubt that Kant's ingenious attempt to provide a transcendental foundation for the scientific knowledge of his time not only reflects the spirit of his time with respect to the extension of "science proper" but also reveals serious gaps within the domain of what was actually accepted as "science proper," though these gaps have been most often ignored in the German reception of the *Metaphysical Foundations* up to now.[16] A look at Fries's *Mathematical Philosophy of Nature* may contribute to a more complex picture.

Fries's principal work concerning the philosophy of science is divided into two parts: I will deal later with the first part, on the "philosophy of pure mathematics."[17] The structure of the second part, on "pure theory of motion," already shows that it is guided by Kant's *Metaphysical Foundations* but that Kant's work by no means determines Fries's approach to the philosophy of the different sciences: (1) "phoronomy," (2) "foundations of dynamics," (3) "foundations of mechanics," (4) "foundations of stoichiology" (*Stöchiologie*) or "foundations of the doctrine of the kinds and compositon of masses," (5) "foundations of morphology," and (6) "foundations of phenomenology" (1822, ix–x). Fries obviously accepts Kant's *Metaphysical Foundations* as the starting point of his investigations (1–3, 6), but not as sufficient (4, 5) (1822, 411–412).

Mathematical Physics

Kant's *Metaphysical Foundations* are synthetic not only in an epistemological sense (synthesis of a priori concepts) or a methodological, especially Newtonian sense ("proved" explanations of phenomena and special laws by deduction from principles), but also in a traditional mathematical sense (relying on Euclidean geometry). The analytical tradition of mechanics goes back to the late seventeenth century, and achievements like the principle of least action, the principle of virtual velocities, and various forms of conservation laws—especially, of course, the conservation of mechanical energy for a large class of mechanical systems—might have shown Kant that conceptual foundations of mechanics fundamentally different from Newton's may well have been possible. And yet, this strand of mathematical physics is totally absent from the conceptual analysis of his *Metaphysical Foundations*. Its philosophical relevance was not acknowledged in Kant's critical period at all.[18]

Fries by contrast appreciated this development in the foundations of mathematical physics manifest especially in the works of Leonhard Euler, Pierre Louis Moreau de Maupertuis, Jean le Rond d'Alembert, Joseph Louis Lagrange, and Simon Denis Poisson. Both in his phoronomy (1) and in his mechanics (3), Fries refers to their approaches as alternative, that is, essentially non-Newtonian frameworks of mechanics. The *Mathematical Philosophy of Nature* is in fact probably the only German work in the first half of the nineteenth century in which this divergence of different attempts at the foundation of mathematical physics is reflected at all as a philosophical problem and in which an integration is proposed.

This proposed integration follows Fries's methodological reflections as described earlier: The "constitutive" or "direct" principles of the pure doctrine of motion are, by and large, Newton's laws of motion. Newton's second law is added to Kant's "legislative framework" of the *Metaphysical Foundations* as a conventional stipulation prior to any empirical observations about motion—a priori not in the sense of "condition of the possibility of experience" but in the sense of "necessary to judge given experience," or in more concrete terms: to deal properly with forces and motion (Fries 1822, 402–403; see König and Geldsetzer 1979, 26*). The principles of analytical mechanics, on the other hand, are "indirect"; they are results of "bottom-up-approaches" for systematizing mechanical experience before constitutive principles were found, and they are still useful when applied to mechanical systems with unknown interactions of forces (1822, 399–400, 404–405).[19] Thus Fries stresses the heuristic relevance of these principles according to the regressive method of theory formation: "All theory here starts from experience, but experience does not teach us the laws of motion, but requires us to search for these laws and determine the applications of pure laws to particular phenomena. So, the treatment of particular experiences at first always leads to indirect methods, where not all laws of the acting forces are known" (1822, 404).

Though the constitutive "Newtonian" laws are necessary in order to develop the pure theory of motion progressively and in a "synthesizing" manner, the "integrals of motion" and variational principles of analytical mechanics remain important as heuristic devices and instruments of applying the pure theory to intricate mechanical problems. In general, and with respect to the enormous rise of mathematical physics in the late eighteenth and early nineteenth centuries, Fries stresses the creative and formative role of mathematics for the natural sciences: "For, this science [the pure theory of motion] is actually the armory of all those hypotheses from which later explanations are drawn that have success in experience. Most of it concerns mathematical developments, the basic concepts, however, are of philosophical nature, and should this be successfully communicated to experts of natural science [*Naturkundigen*], we would gain quite a lot for the discipline of hypothesis" (1822, 10).

Chemistry

According to Kant's well-known dictum, it is likely that "chemistry can become nothing more than a systematic art or experimental doctrine, but never science proper" (IV, 471). This expresses neither his lack of appreciation nor his lack of interest in chemistry.[20] It rather highlights the fact that Kant saw no possibility of giving chemistry an a priori foundation that would meet the standards laid down in the *Metaphysical Foundations*, that is, an a priori foundation beyond chemistry's merely empirical generalizations, which lead to empirical rules instead of laws and to regulative ideals instead of fundamental concepts. Though the "chemical revolution" dramatically changed the character of chemistry during Kant's lifetime and especially succeeded in reaching important quantitative laws through the research of A. L. Lavoisier, L. J. Proust, J. Dalton, J. J. Berzelius, J. B. Richter, and others, this was, of course, not sufficient according to Kant's foundational claims.

Fries first discusses the problem of mathematizing chemistry in his *Criticism of Richter's Stoichiometry* (1801). Jeremias Benjamin Richter was a former student of Kant who somehow trivialized his teacher's demand for *mathematical* foundations of natural science (Carrier 1990, 200–201). Though Fries welcomes Richter's attempt to make chemistry a mathematical science (Fries 1801, 135), he firmly criticizes his realization of this aim. His criticism concentrates on two points (1801, 49): First, Richter gives no systematic presentation of stoichiometry but only a rhapsody (1801, 19, 25)—or, to use Kant's phrase, an "aggregate"—because he does not sufficiently reflect the metaphysical foundations of his science. Second, and even more important, Richter does not recognize that mathematics in natural sciences—aiming as it does for a foundation—cannot be applied to arbitrary experience but must be used to construct a priori concepts that make possible the experience relevant to the science in question (1801, 9–10, 13–18, 22–23, 48–49, 88–89). By mistake, Richter applies mathematics to the "art of chemical experimenting," whereas he should have applied it to gain a "theory of chemistry" as a subsystem of the "physical sciences" that is in need of both metaphysical and mathematical principles in order to be accepted as a science (1801, 16–17, compare 18–19, 89, 118). And in order to reach a pure theory of chemistry, Fries argues, proper mathematical principles must enter at the level of dynamics in Kant's sense (1801, 14–16). As Richter does not recognize the importance of dynamics for his "Kantian project," and especially underestimates the complexity of forces acting in chemical compounds, the quantitative regularities he finds in his "mass rows" (*Massenreihen*) can at best be compared to Kepler's laws of planetary motion, for which a Newton had yet to come (1801, 121–122, compare 17–19, 116).[21]

In the part of his *Mathematical Philosophy of Nature* devoted to "stoichiology" (1822, 540–571),[22] Fries tries to develop a dynamical foundation of chemistry: "The kinds of masses must not be separated according to mechanics . . . but according to dynamics, that is, according to the different relations of their fundamental forces. So the concept of *substance* (in the chemical meaning of the word) becomes meaningful to natural philosophy" (1822, 540). In his theory of fundamental forces, Fries adopts Kant's double dichotomy of attractive and repulsive forces on the one hand, penetrating forces (*durchdringende Kräfte*) and contact forces (*Flächenkräfte*) on the other hand. But contrary to Kant, Fries takes all four kinds of fundamental forces into account: attraction and repulsion at a distance, attraction and repulsion in contact (1822, 543–547, compare 451–453, 620–622). Though Fries's elaboration of this considerable deviation from Kant's dynamics cannot be discussed here, it should be noted that, according to Fries, the "gap" between the essentially mathematical level (1822, 451–452, 621–622) of constructing proper forces and the level of chemical phenomena cannot be bridged without leaving space to conjectures and hypothesis: "The future development of science will decide if hypotheses of this kind are useful or not. In any case all processes of gravitation as well as all phlogistic and chemical processes have to be explained by universal penetrating forces and contact forces" (1822, 571). Chemistry may thus not become a proper science according to Kantian standards, but is definitely a science according to Fries's "methodological extension," because it can be developed in the form of theory.

BIOLOGY

In his "foundations of morphology" (1822, 572–600) Fries also transcends Kant's realm of "science proper." Part of it is a "theory of morphotic processes" (*Theorie der morphotischen Prozesse*) or of "natural drives" (*Naturtriebe*) (1822, 584–585), as he calls it in a rather misleading manner. The designation "natural drives" is misleading, because it suggests an animistic or even anthropomorphic understanding of organic processes that Fries seeks to avoid and that he criticizes throughout his philosophy of biology (see Fries 1813, 394–400).

Morphology has to do with the forms of those interactions of physical bodies which cannot sufficiently be explained by fundamental forces alone (1822, 581). It is not restricted to organic processes, but is relevant already for a constitutive theory of mathematical physics, like celestial mechanics. In order to explain the movements of planets along conic sections, for example, the law of gravitation is not sufficient but must be accompanied by considerations of the configuration of the system or, to use mathematical terms, by the consideration of initial and boundary conditions. The aim of morphology is a mathematical classification of the different types of these conditions in order to distinguish different forms of physical interaction under the same fundamental forces. As far as they are relevant to a causal explanation of physical interactions beyond the fundamental forces, these conditions are designated by Fries's unfortunate notion of "natural drives" (1822, 582).

Now, the mathematical philosophy of nature must construct its different kinds mathematically. In the case of living plants or animals the accomplishment of this program may create immense mathematical and empirical problems. It will be essential, however, that one never introduce "an unexplainable fundamental force for certain substances, namely organic matter," but that instead one always strive for "an explanation in terms of a law that governs a certain kind of interaction in the world of physical bodies" (1822, 583). Fries thus rejects vitalism, but also the use of a material or "objective teleology," in order to explain organic processes. This kind of teleology was criticized but not always avoided by Kant. In contrast, according to Fries's twofold (that is, progressive and regressive) way of developing theory, this kind of teleology can always be used as a heuristic device in the regressive approach. In other words, this teleology can be used in order to reach scientific explanations by fundamental forces and morphotic structures, but always has to be excluded in the progressive approach, that is, as an explanation in its own right (1822, 597–598).[23] Without going into the details of Fries's methodology of biology, one might say that the appearance of a "Newton of the blade of grass," which seemed impossible to Kant (§75, V, 400) was no mere utopia to Fries but seemed reachable one day by the application of his direct and indirect approach. Fries's adherent Matthias Jacob Schleiden, botanist and one of the founders of modern physiology, later made abundant and successful use of this methodology in biology (Schleiden 1989; see Charpa 1988 and 1999).

Pure Mathematics

Of course, Fries accepts not only Kant's premise that mathematics is decisive for reaching a proper understanding of natural phenomena, but also his premise that mathematics is of philosophical interest in its own right. Therefore it is not by accident that the whole first half of Fries's *Mathematical Philosophy of Nature* deals with "philosophy of pure mathematics" (1822, 33–395). Though this subject is actually beyond the scope of this paper,[24] some remarks about its character may show that its development fits the general objective of Fries's philosophy of science, that is, to "modernize" Kant's approach in light of actual scientific developments.

For internal as well as external reasons (especially the rise of neohumanism), German mathematics in the first decades of the nineteenth century was strongly oriented toward "pure" mathematics. This pure mathematics was sharply distinguished from sensory experience and aimed at rigor beyond questionable intuitive foundations. Therefore, arithmetic and algebra, rather than geometry or mechanics,[25] become models of mathematical research. The growing autonomy, abstractness, and "symbol-ladenness" of mathematics leads to doubts about Kant's understanding of mathematical concepts as mere constructions in space and time.

Fries seems to be not only the first German-speaking philosopher who explicitly asked for a philosophy of mathematics as a metatheory of pure mathematics (see Pulte 1999a, 74), but also the first to work out such a metatheory as a "complete system of mathematical forms" (1822, 50).

According to him, the two principal problems of this metatheory are the origin of mathematical knowledge and the foundational claims of mathematics in the context of all human convictions (1822, 48). With respect to the new developments within mathematics, which Kant did not reflect, two characteristics of his approach are worth mentioning, namely, his introduction of "syntactics" and his modification of Kant's understanding of mathematical apodicticity.

First, Fries clearly differentiates between a "syntactics or theory of combination [*Kombinationslehre*] as a theory of the pure laws of arrangement of given parts" and the "theory of numbers, arithmetic, which is based on the idea of wholeness composed of homogenous parts" (1822, 65). Arithmetic is more restricted than syntactics in so far as it composes its objects (that is, numbers) from a special syntactical postulate (homogeneity), though our productive imagination allows for other forms of composition (1822, 68). One can undoubtedly trace back to the works of Carl Friedrich Hindenburg and his so-called "combinatorial school" Fries's view that arithmetic aims at a measuring determination of magnitudes by concepts of pure intuition and is preceded by a regulating syntactics that is interested in the construction of the "most general mathematical concepts" and is not based in intuition.[26] This view takes up and develops Euler's and Lagrange's algebraical foundation of analysis:

> That syntactics is in principle independent of arithmetic is decided among us since Hindenburg. The task of syntactics is putting in order, the task of arithmetic is measuring. To syntactics belongs no separate purely imaginative [and] fixed sequence; but only the peculiar operation of productive imagination, that is, putting in order. Therefore syntactics has no axioms, but only postulates. In contrast, arithmetic borrows its postulates from syntactics, but has its separate fixed sequence of the larger and smaller and separate axioms for this. (Fries 1822, 68)

In Fries's philosophy of mathematics syntactics becomes a second basic discipline next to (and in a way prior to) arithmetic. The first creates more "qualitative" mathematical concepts (one might think of B. Riemann's later concept of an *n*-dimensional manifold), while the second creates more quantitative concepts (such as numbers and magnitudes).

It fits into this context that in Fries we encounter second (and more generally) a separation between pure intuition and mathematical apodicticity. Admittedly, mathematical knowledge that is different from philosophical knowledge is not given to us by thinking, but "already by itself in clear intuition. To realize, however, its universality and necessity I need thinking"

(1837, 417). It is therefore right to say that Kant's "apodicticity dualism" of intuition and thinking is replaced by an "apodicticity monism" of thinking in Fries's philosophy of mathematics (see Ende 1973, 35). For Fries, all apodictic knowledge is "discursive, philosophical knowledge as well as mathematical knowledge" (1837, 412).

This thesis only seems to signify a restriction of the Kantian meaning of apodicticity: By substituting the productive imagination as foundational authority for pure intuition, Fries actually opens the field of mathematical apodicticity to such propositions that have no foundation in Kant's pure intuition. He thereby takes into account the general development of mathematics in his time, which is characterized by an increasing abstraction and self-reference of its laws and by the complexity of its structures.

Fries did not (and, for several philosophical reasons, could not) extend his originality to the foundations of geometry and therefore remained strongly in favor of one (and only one) axiomatic system of geometry, that is, Euclid's (1822, 355–380; see Gregory 1983a, König and Geldsetzer 1979, 63*–69*). Nevertheless, his philosophy—and especially his philosophy of mathematics—found strong supporters among mathematicians. C. F. Gauß, for example, praised his work as exceptional and lucid in times of growing philosophical obscurity (König and Geldsetzer 1979, 39*–40*).

CONCLUSION

My outline may have shown that Fries's rather limited impact on later philosophy of science stands in remarkable contrast to his actual achievements in this area. It may have also indicated at least one important reason for this discrepancy: Fries's approach aims at establishing an autonomous philosophical metascience that develops in close contact with science. Philosophy of science can neither replace scientific research nor become superfluous owing to scientific developments—both areas are, on the contrary, complementary and interacting. In a way, however, this model was too modern to be successful in his time. While German academic philosophy and its historiography stuck to the idea of the predominance of philosophical speculation over empirical research, most practicing scientists turned away from German "school philosophy" and considered science and its history from the point of view of naive positivism. Neither view could perceive and appreciate Fries's peculiar approach and his achievements. Neo-Kantianism, however, could have done so, but frequently lost sight of a respectable part of its (potential) history when it followed nearly unanimously O. Liebmann's slogan "back to Kant." Among other reasons, this historical development contributed to the neglect of the philosophy of science in the tradition of Fries and his adherents (Ernst Friedrich Apelt, Matthias Jacob Schleiden, Oscar Xaver Schlömilch, Leonard Nelson, and others) up to now. But as Ernst Cassirer put it:

> It is his [Fries's] and his pupil Apelt's decisive merit that they . . . related the fundamental question of philosophy again to the "fact of science" and thereby brought it back on a strictly scientific ground. . . . what Fries and Apelt did for the elaboration of Kant's doctrine of synthetic principles, what they did especially for the understanding of particular fundamental concepts and fundamental methods, remains valid and has to be accepted also by him who rejects Fries's "anthropological" criticism as a foundation of philosophy. (Cassirer 1923, 482–483)

Notes

1. For biographical information, see Frederick Gregory's chapter in this volume; Mourelatos 1967 gives a short but informative overview. The standard biography on Fries is still Henke 1937. The last volume of Fries's complete works (*Sämtliche Schriften*) (1967–), however, will contain rich additional material on his life and work. Glasmacher (1989) provides a valuable bibliography on Fries and his school up to 1988.

2. J. F. Fries to an unknown recipient, 21 September 1832 (letter no. 1177, to appear in the final volume—volume 29—of Fries's complete works).

3. I do not take into account here Kant's *Opus postumum* (especially his *Transition from the Metaphysical Foundations of Natural Science to Physics*) as it was largely unknown at the time. For Kant's later philosophy of science, see Friedman 1992, 213–241.

4. I return to the first two examples below. For the calculus of probability, see Fries 1842.

5. The bibliography includes his most important contributions to the natural sciences and to philosophy of science. Useful presentations of this part of his work can be found in Amir-Arjomand 1990, Hermann 2000, and, above all, König and Geldsetzer 1979.

6. I will take up and shorten Kant's paraphrase given in this passage and use the term "subjective formal teleology." See also Kant's first Critique (A620/B648ff).

7. Ahndung literally means "presentiment" but is used by Fries also in the meaning of "aesthetic sense." See Fries 1805, 601–755. In the following analysis I draw on Pulte 1999b, 330ff.

8. As a proper understanding of Fries's notion of "theory" depends to a certain extent on the frame described here, I will postpone a discussion of it to the next section.

9. The latter are also called "maxims of the sytematizing understanding" (e.g., 1828–1831, 5:323). Both ideal regulatives and heuristic maxims can be considered fission products of Kant's subjective formal teleology.

10. See Fries 1822, 397–690, where the pure doctrine of motion is treated in a sense close to Kant's phoronomy (in the first chapter of the second part, 397–442); see also the section "Mathematical Physics" below.

11. "This science is in a way the philosophy of applied mathematics. The pure doctrine of motion . . . is mathematics applied to metaphysical knowledge; it contains the system of the whole [and] complete scientific knowledge of man" (1822, 397; cf. 3, 10).

12. Fries regards celestial mechanics as an exception; I will come back to this point.

13. For the following summary, compare Fries 1828–1831, 5:325–332, and 1837, 426–433.

14. Compare the section "Fries's framing of the argument" above. Fries's consideration can be illustrated as follows: A heuristic maxim serves to generalize a hypothesis about a field of experience that conforms to certain a priori constraints, because speculation supplies a structural framework of conditions that have to be obeyed in the construction of a hypothesis. If one of the hypotheses can be confirmed by eliminative induction, it is constitutive in so far as it contains new cases of application that were not considered before. Newton's law of gravitation was framed as a hypothesis with respect to the system earth-moon. In the sense described above it becomes constitutive with respect to other systems (like sun-earth).

15. A subtle analysis of this antagonism is given in Bonsiepen 1997; see also Gregory 1983b and 1989.

16. I would like to refer to Kant's omission of Newton's second law of motion in his attempt to give a foundation of mathematical physics. Kant does not try to give an a priori derivation of this law—which would be crucial for a foundation of rational mechanics in general. Moreover, this point is not discussed in a number of books devoted to Kant's *Metaphysical Foundations*. See, for example, Gloy 1976, Plaass 1965, and Schäfer 1966. For a reasonable analysis of this point (and conflicting interpretations), see, on the other hand, Pollok 2001, 387–388.

17. Fries 1822, 33–395; see the section "Pure Mathematics" below.

18. However, for the role of teleology (and especially the principle of least action) in his precritical period, see Buchdahl 1969, Waschkies 1987, and Pulte 1999b.

19. In some cases, as in the theory of capillarity, for example, the "indirect method" even seems indispensable in order to find the correct laws of the interacting forces; see Fries 1822, 408.

20. On the contrary, Kant's work—especially the *Opus postumum*—underpins his strong interest in foundational questions of chemistry; see Carrier 1990 and Friedman 1992, 264–290.

21. In later works, Fries was much more favorably disposed toward Richter's stoichiometry, obviously because he saw how difficult it would be to modify Kant's dynamics according to the demands of quantitative chemistry; see, for example, Fries 1822, 644, 654, and 1826a, 15–16, 52, 248–249; compare also Henke 1937, 49.

22. Fries uses the notion "stoichiology" as a synonym for "chemistry." See Fries 1826a, 15.

23. In Kant's application of teleological arguments in the realm of organic processes, Fries finds important evidence for his thesis that Kant did not sufficiently distinguish ideas (where teleology may be used) and theories (where teleology must be forbidden), that is, the ideal and the natural worldview (see section "One System, Various Theories" above, also Pulte 1999b, 327–329).

24. Several aspects of Fries's philosophy of mathematics are discussed in König and Geldsetzer 1979, 36*–69*, Gregory 1983a, and Schubring 1990.

25. It seems worth mentioning, however, that in the field of mechanics the orientation to "pure" mathematics leads to a conventional interpretation of mechanical principles half a century before Poincaré transferred his conventionalism from geometry to mechanics; see Pulte 2003, chaps. 5 and 6.

26. Hindenburg's school and its relevance for early nineteenth-century German mathematics is discussed in some detail in Jahnke 1990, 161–232.