THE TRANSFORMATION OF SCIENCE IN GERMANY AT THE BEGINNING OF THE NINETEENTH CENTURY

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Physics, Mathematics, Poetry, and Philosophy

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and
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With a Foreword by
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Preface

On July 20, 1794, two men on their way home from a meeting of the Jena Naturforschende Gesellschaft, engaged in a spontaneous discussion about the existence of an "archetypical plant" (*Urpflanze*). This seemingly casual conversation was documented in one of the most important autobiographical accounts of the early 19th century. Published as "Glückliches Ereignis" ("A Happy Coincidence") in 1817, the scene is memorable because of its far-reaching consequences on the one hand, and on the other exactly because its purported insignificance is so characteristic for its time (Goethe 86-90).

Of course anyone at all familiar with 18th century German intellectual history will immediately identify this "Happy Coincidence" as the first encounter between Johann Wolfgang Goethe and Friedrich Schiller. It was this dialogue that launched the *Wunderjahr in Jena* ("Miracle Year in Jena") which Theodore Ziolkowski traced so meticulously in his fine monograph a few years ago. It also marked the beginning of a decade of intense collaboration between the two men, ended prematurely only by Schiller's death in 1805. As a result, the scene Goethe described almost 25 years later is indeed one of the most important memory sites of German literary history—exactly the reason why it has been recounted time and again.

At the same time, it is also an important milestone in 19th century natural history. It's easy enough to forget who was talking with whom, what was being discussed, and what arguments were used. Botanical questions were surely only of superficial interest that evening, and the conversation most likely quickly morphed into a discussion of natural philosophy. Schiller quite rightly pointed out that what they were debating were fundamental epistemological questions. With regards to the archetypical plant, Goethe reports, Schiller merely commented: "That's not an experience, it's an idea"[1]--deftly juxtaposing empiricism and speculative philosophy. Above all, it is important to point out that neither considered himself an expert, not in philosophy or in the natural sciences.

Educated as a lawyer, Goethe had spent the previous two decades in public service; as minister of the Duke of Weimar, his portfolio included education, mining, armed forces, and road construction. Schiller, who had never attended a university, had been professor of Universal History at Jena University since 1789. In 1794, he had abandoned his remarkable career as a dramatist, focusing instead on philosophical and historical writing. The seriousness and fervor with which Goethe and Schiller discussed the natural sciences, demonstrate that at the time, these questions were at the forefront of intellectual discourse and by no means limited to a handful of specialists: the stage was open to everyone and intellectuals from many disciplines acted on it, each contributing in their very own way. Their lively participation raises the question: What was natural science around 1800—art, science, or philosophy?

The contributors to this volume address the issue using physics as an example. The essays present two different approaches: a reconstruction of the development of natural science and physics at that time on the one hand, and a demonstration of the complexity of their unfolding on the other. If it is true that scientific research around 1800 was central to the development of modern science as we know it today, this applies especially to physics.

The investigation of nature demanded the development of new standards of observation as well as a new and expanded terminology to describe it. Discoveries made about phenomena like electricity, galvanism, or magnetism ultimately required that the traditional approaches based of Aristotelian physics be expanded to accommodate a more modern understanding of physical nature.

During their first encounter in Jena, Goethe had approached the issue from a biological perspective while Schiller had argued philosophically. The essays in this collection follow a similar trajectory, attempting to delineate boundaries that, in many instances, remain diffuse. As a result, they investigate a knowledge area permeated by many different epistemic discourses. The topic, which engaged scholars as different as Friedrich Wilhelm Joseph Schelling and Achim von Arnim, Abraham Gottlob Werner and Jakob Friedrich Fries, proved so effective and influential exactly because it could be approached from so many perspectives.

The resulting discourse not only paved the way for a natural science organized according to different disciplines. It also led to the establishment of physics as an academic subject at universities. At the same time, it proved fruitful for literature and philosophy, disciplines that thrived exactly where Goethe and Schiller had met, creating a cultural fulcrum for Europe around 1800 (Breidbach and Ziche; Breidbach, „Ende Ereignis“).

Both developments, so aptly documented in this volume, were taking place simultaneously. In fact, they presuppose each other, interact with each other, are interdependent. In an important way, the collection reconstructs the constellation of natural science around 1800, dismantling the well-worn cliché of a speculative philosophy and an empirical natural science that began to move further and further away from each other, ultimately becoming irreconcilable. Such an interpretation of the development of a physical-philosophical discourse into different disciplines superimposes the dualistic viewpoint of our own time onto an era where erecting such categoric boundaries between knowledge areas was completely foreign. Herein lies the valuable and important contribution of this volume to the discussion of physics around 1800.

The sequence in which the research is presented is convincing. The questions asked by "physicists" around 1800 were questions asked in many other areas of society. They are not only questions about nature, but about mathematics, philosophy, and last but not least, poetry and literature. From a contemporary perspective, this volume brings together a surprising (but necessary) number of scholars from different disciplines: physicists and science historians, philosophers and literary scholars—all contribute to the plethora of observations and arguments presented in this collection. Another "Happy Coincidence" which, like Goethe's almost 200 years ago, leaves the reader with the hope that even in our age, where knowledge areas are getting more and more differentiated, a meeting of different minds could occur, fuelled solely by a curiosity about the essence of nature.

STEFFEN SIEGEL

NOTES

1. For a more detailed discussion see Breidbach, Goethes Naturverständnis.

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—, and Paul Ziche (eds.): *Naturwissenschaften um 1800. Wissenschaftskultur in Jena-Weimar*. Weimar: H. Böhlau, 2001. Print.

Foreword

The essays in this collection were presented in a symposium we organized in 2009. Appropriate to the topic, the setting was the Ernst-Haeckel-Haus of the Friedrich-Schiller-Universität Jena, home of the museum and archives of the Institut für Geschichte der Medizin, Naturwissenschaft und Technik. Her research on Achim von Arnim's scientific writings introduced Roswitha Burwick to Olaf Breidbach's project *'Empiricism versus Speculation'* within the frame of the special research program *Ereignis Weimar-Jena. Kultur um 1800* (Sonderforschungsbereich 482), which brought together philosophers, humanists, scientists, and historians of science to discuss a range of interdisciplinary topics relevant to the intersections of our areas of research. Our symposium was designed as a forum where representatives from various disciplines gathered to explore ways in which the interrelations of our research could initiate new modes of inquiry. Most importantly, Achim von Arnim joined writers like Novalis (Friedrich von Hardenberg) and Johann Wolfgang von Goethe whose scientific writings had been an integral part of their aesthetics.

Discussions within the framework of the Sonderforschungsbereich 482 *Ereignis-Weimar-Jena. Kultur um 1800* focused on a series of concepts that existed side by side in physics and aesthetics, organizing and systematizing the natural and the aesthetic in various ways. A comparison of Novalis, Arnim, and Johann Ritter indicated that in the period around 1800 the boundaries of aesthetics—conceived as a comprehensive doctrine of perception and physics—could not be drawn in a natural science, which became increasingly analytical. The field of physics around 1800 ventured into new dimensions of experimentation with Ritter as its representative and demanded the integration of a multitude of previously unknown phenomena into the traditional structures of perception. That endeavor was thwarted because electricity and magnetism were beyond the boundaries of an Aristotelian physics.

The experience of forces—a fundamental principle of natural processes—now required new definitions of traditional concepts in physics. How could this be achieved if not through a meticulously executed mode of intuition operative in all the new discoveries? If, however, nature was now guided by intuition, was the tradition of intuition still firmly rooted in aesthetics? Can language be found that describes what has not yet been described, that represents phenomena which only visualize the effect of a latent network of tensions? Could this kind of representation be the model for concepts that were not yet conceivable in analytical thought? Could physics be represented as *physis*?

Around 1800, a new order of nature was established that blurred—at least for the moment—all categories or orders of knowledge. It is therefore not only crucial to reconstruct modes of knowledge around 1800; it is equally important to realize that we are still persisting in that same tradition (Breidbach and Rosa). Assumptions of boundaries between emotion and knowledge continue today, informing the discourse that links art, science, and philosophy. Our investigation is as significant for Achim von Arnim's physics and his participation in the scientific discourse as it is for the prominent minds of English Romanticism: Samuel Taylor Coleridge, Percy Bysshe Shelley, John Keats, or William Blake. By exploring the intersection of art, science, and philosophy, we also hope to accentuate the impact of the arts and the humanities on science from 1800 to the present.

For years, Burwick has argued that Arnim's scientific studies at the universities of Halle and Göttingen shaped his aesthetics and are vital for an understanding of his narrative structures and *Weltanschauung*. She also contended that his understanding of natural science was linked to the group of philosophers and practitioners of science in Jena around 1800. Arnim not only corresponded with Friedrich Wilhelm Schelling and Ritter but was also deeply engaged in the discourse about materiality of substances, forces, as well as experiential and experimental science. Our symposium brought all of these strands together by expanding the notion of scientific aesthetics (Ritter) to the concept of aesthetic science, precisely what Arnim practiced in his scientific essays and his literary texts. Among the prominent poets of the same period in England, it was Coleridge who pursued the current developments in physics and perused the scientific reports in the *Philosophical Transactions* of the Royal Society.

To capture the discourse and broaden the scope of inquiry, we decided to publish two volumes: one in German under the title *Physik um 1800. Kunst, Wissenschaft oder Philosophie?* and one in English that selected contributions from the German collection but added also some essays in English. Among the essays translated for the English version, we included Schelling and Goethe, well known for their interdisciplinary endeavors, and additonally the philosopher Jakob Friedrich Fries and the scientist Abraham Gottlob Werner, less well known but nevertheless essential for the discourse of the time.

Olaf Breidbach's essay on Schelling's speculative physics re-evaluates Schelling's program of idealistic *Naturphilosophie* and argues that speculation and empiricism were not opposing forces but existed side by side. Speculative physics is therefore not esoteric but a doctrine of science that is in line with the attempts of natural scientists to find a methodology for a structure that could expound the interrelationships among the sciences. It was Schelling, the philosopher, who wanted to provide the physicist with a model that was not available to him in the multitude of phenomena. To fill the gap in the methodology of Kantian philosophy, Schelling charted a transcendental philosophy and chose as the starting point a still undetermined domain of philosophical argument, namely, "the questions concerning the representation of our experience of nature."

While Goethe's works have been translated into English, only a few of Arnim's novellas are accessible to Anglo-American readers (Duncan, Dickson). Although named as a surrealist poet by André Breton, none of Arnim's major novels, his poetry, or his essays have made it into the canon of the English-speaking world. This is mainly due to his complex style, imagery, and intertextual frames of reference that remain challenging even to a German-speaking readership. With the exception of two essays in English (Burwick, *Damnation*; Burwick and Burwick), all research about his scientific oeuvre has been published in German. My contribution to the discussion of the topic of Physics around 1800 provided me not only with the opportunity to insert Arnim into the Anglo-American discourse on literature and science; it also gave me the space to quote extensively from the published volume (WAA 2) as well as the unpublished manuscripts (WAA 3) to demonstrate how his scientific studies are an integral part of his aesthetics.

Judith Grabiner's essay on "Mathematics around 1800" outlines the history of mathematics as important for science and, at the same time, as independent from science. The essay provides links to Schelling, Fries, and Arnim in that it highlights their efforts to demonstrate the impact of mathematical natural philosophy and the need for applied mathematics to quantify imponderable substances and forces.

Helmut Hühn's discussion of Goethe's connections between the study of nature, history of science, reflections on art, and social analysis in his novel *Die Wahlverwandtschaften* explores the complexity of Goethe's transformation of scientific concepts into poetic form. While the notion of "elective affinities," as argued in previous interpretations of the novel, suggests Goethe's appropriation of the term from the prevalent chemical discourse, Hühn points to the contradiction of the narrated plot line and the doctrines of the natural sciences: in the end, all characters are not reordered into different relationships but become radically isolated individuals.

Andre Wakefield's article "Abraham Gottlob Werner: Money, Romance, Classification" places Werner "at the very epicenter" of the emerging movement of "romantic science" around 1800 that influenced writers like Novalis and *Naturforscher* like Alexander von Humboldt. At the same time, Werner was the representative of "Enlightenment science," who was interested in the classification of basalt formations and the founding of mining academies with their strictly enforced goal of training dedicated mining officials. Less interested in exploring the depths of the earth, they were considered servants of the sovereign treasury (*Kammer*) and part of the larger cameralist tradition in Freiberg.

In his essay "Jakob Friedrich Fries on Inference Types in the Natural Sciences," Temilo van Zandwijk investigates Fries's program of logic as a methodological doctrine where the relation of mathematical construction and empirical intuition clarify and counteract a reductionist understanding of natural science. Through separating feeling and reflection from science, Fries was nevertheless able to accept connections between aesthetic and scientific conceptions of the world.

Although we were not able to include a complete set of translations of all the original German essays in the English version of the project, we were fortunate to add two essays on English literature and science thus expanding the scope of inquiry. Dometa Wiegand Brother's discussion of the "Physics of Coleridgean Romanticism" and Kathleen Lundeen's article on "The Collision between Physics and Metaphysics in England around 1800" insert English writers, philosophers, astronomers, and their understanding of Newtonian physics into the range of topics that the collection illustrates.

Lundeen argues for a turn of the differentiated/undifferentiated paradigm in the late eighteenth century when it was challenged by Joseph Priestley and Friedrich Wilhelm Herschel. Her analysis of the correlation between English romantic poetry and twentieth-century physics extends the dialogue and shows how liberation from the paradigm was essential to the romantic poets' ability to free themselves from the Newtonian universe.

By tracing the influence of Leibniz and Newton on Coleridge's ideas of cosmologies of matter and movement, space and time, Wiegand Brothers provides an innovative reading of Coleridgean poetry through the "lens of the debate between the material Newtonian system and the theoretical relativistic system of Leibniz."

Both Olaf Breidbach and Gerhard Wiesenfeldt (University of Melbourne, Australia) have been instrumental in shaping Burwick's research and advancing a project that continues to be challenging as she is now completing Arnim's *Naturwissenschaftliche Schriften II* (WAA 3), which contains approximately 1000 pages of previously unpublished manuscripts. The continued support by Breidbach and his research-team, the symposium, and the two publications demonstrate our common interest in interdisciplinary work as well as the genial productivity of international collaboration and personal friendship.

Our collaboration benefitted immensely from our partnership with colleagues, friends, and the authors themselves. We are especially indebted to Josef. G. Steinebach, Universität zu Köln, who edited the German translation of Judith Grabiner's essay on eighteenth-century mathematics. John Vivian translated several of the essays into English and Katharina von Ankum translated the Preface. Burwick's translations draw mainly on terminology available in philosophical texts in translation (Schelling). Katie Van Heest, Tweed Editing, copy-edited the collection; Chelsea Carlson and Hillary Shipps designed the layout and Kristin Oegema completed the formatting. Last but not least, we would like to thank Karola A. Schrader, Ernst-Haeckel-Haus, for her patience and congeniality.

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Introduction
Physics around 1800. Art, Science or Philosophy? An Approach

OLAF BREIDBACH AND ROSWITHA BURWICK

"Early Romanticism in Jena," the period around 1800, when a variety of thinkers, ideas, and beliefs were intersecting in Jena, is especially interesting in the context of the development of our European notions of order and structures of knowledge (Poggi). While various movements existed side by side and aesthetic, scientific, and philosophical thought patterns were not yet distinguished, the idea emerged to take the whole of experiential interconnections into account.[1] This is important not as a contrast between a culture of science that is organized according to disciplines and a culture that we understand today in its coexistence with knowledge: what we call simply *Jena Romanticism* is rather the point of origin of our contemporary views of science and knowledge. In other words, the concepts negotiated around 1800 in Jena are the beginning of a consolidation of ideas and structures that still determine the sciences today.[2] Discussions in Jena shaped the dimensions that raised the consciousness about the practices of experiential sciences, specifically in the debate with speculative philosophy; it was at this moment in time that a distinct, disciplinary methodology of thought and research could be developed.[3] What was negotiated in Jena around 1800 does not belong to the past; rather, the past is the beginning of a development of concepts about rationalities and rationalization that are still valid today. Here the patterns were established, which the sciences of the nineteenth and twentieth centuries have since applied.

Ziolkowski talks about a *Wunderjahr in Jena* ("a miracle year in Jena") and defines a period when people not only congregated but realized in their encounters an abundance of important conceptions within a very short time. The foundation for these innovations was a concurrence of styles and approaches of thought that we find only in isolation today.[4] This specific situation provided the framework for Dieter Henrich to show constellations that were effective in Jena, and to make these developments in eighteenth-century philosophies transparent. Henrich argues that in direct interaction a variety of concepts were discussed, negotiated, and structured in a specific way. In Jena around 1800, the disciplines that compose our landscape of knowledge and science today were not structured in clearly defined categories but situated within an all-encompassing frame of reference. Consequently, they were grounded in their arrangement with reference to this conceptual frame. Thinking in disciplinary terms—as practiced today—where individual premises can be verified in distinct disciplinary methodologies, had to be developed first. Shapes and forms of the sciences guiding our research today had their origins in the discourse in Jena around 1800 that sought a comprehensive rationale for nature and experience (Breidbach, "Culture of Science").

Around 1800, we find in Jena an abundance of efforts that address systematization in terms of parallel or relational order to comprehend the multiplicity of the natural (Breidbach and Ziche). The goal was to view nature through the perspective of aesthetics, philosophy, or the history of nature and to think about these different aspects in all their detail. That is the reason why all particular views that are negotiated still conceive the whole as not yet split into disciplinary perspectives. Goethe's approach of finding access to nature as a whole was significant and became a guiding principle in and around Jena (Seamon). Goethe was not interested in the alternatives of a scientific or aesthetic perspective but conceived a design that was based on the contiguity of experiences that can be found within the whole (Manger). In contrast to this position, a line of thought is developed in Jena's approach to *Naturphilosophie* that reflects on the idea of a comprehensive perspective in order to integrate it into a system of rationally constructed interrelations. This did not exist side by side with experience and a science that systematized such experience; it was more interested in combining these sciences that systematized experiences into an all-embracing organization of interconnections. These interconnections, however, could only be comprehended conditionally. The natural philosopher Schelling carried the rationality of a mere systematic design in his *System des transcendentalen Idealismus*, published in 1800, into the immediate intuition (*Anschauung*) of a system of order that could not be traced back to an established system of classification (Frank, *Einführung in Schellings Philosophie*). Experiential sciences discussed among each other whether it could be possible to integrate their judgments—which were based on experience—into such a system or whether they had to keep open those experiences that were possible but not yet determinable. At the same time, they started to align themselves in closer circles and to limit the possibilities of experience that were, from their disciplinary perspective, predictable. In the discourse about methodologically constituted disciplines, a new order of relations of the sciences was emerging; although it was defined within disciplinary perspectives, it still adhered to the discussion of an interconnection between the individual disciplines that aimed to comprehend the whole of experiential connections. While disciplinary perspectives remained open in view of their goals, discussions about the structures where certainty could be found in individual sciences were converging around 1800.

When disciplinary boundaries of knowledge, determined during the nineteenth and twentieth centuries, are questioned again today, when unified systems of orientation have to be re-examined because new guidelines have been introduced, a retrospection of the situation around 1800 becomes interesting, and not only for sentimental reasons. Not that an ideal condition of knowledge about the natural would be tangible—such as a Rousseau rewritten in terms of science—or allow the comprehension of nature not as uncomplicated but as a limited resource.[5] At stake is a multitude of alternative solutions that can outline a possible discourse and simultaneously point out what kind of perspectives and structures around 1800 are still valid today.

Establishing a coherent pattern of the world that goes beyond individual disciplines and understanding the interconnections (*Vernetzung*) of disciplines have become an essential task of the humanities, especially in recent years. At the same time, efforts toward an integration of knowledge are made that aim at abolishing the separation of the humanities from the natural sciences and reconnecting them into a new and unified understanding of the world (*Weltverständnis*; Breidbach, "Brauchen die Naturwissenschaften"). However, not only various disciplines but also different cultures claim boundaries that are dominated by their own autonomous systems of validation. Hence, criteria for demarcation provide the argument for specific methodologies or systems of values that are situated in unmediated and autonomous relation to each other. A taxonomy that is all-encompassing in its traditional classification is apparently no longer necessary for this coexistence. This arrangement of parallel systems of validity in reference to individual disciplines can be illustrated with physics. In relativistic cosmology, a coexistence of systems of inertia (*Inertialsystem*) and independent systems of scaling (*Skalierung*) can be postulated so that within physics a correlation of such systems under an overarching scaling is not possible. In spite of this, a discipline is able to work with this multiplicity because it does not represent it in an absolute scale but in a parallel system of equivalent scales. Consequently, the image of a modest rationality emerges out of the expansion of the narrower methodological frame of a discipline; it reflects in the multiplicity of structures various traditions that it can no longer connect with each other but that it respects in their historically determined order.

Based on such concepts, sensitivity is required to deal with these various rationalities; in this context, it is necessary to define the boundaries of value systems so that a validation of individual statements can be found that are congruent within the framework of methodologies of disciplines and cultures. This way, a multiplicity of demands for and attributions of values can be found that can be applied to coexisting disciplines. They are mature within a rationally structured science. Consequently, they can be traced back historically to common roots. Within the individual methodologically established fields, equally structured strategies of assessment are applied. At the same time, the claim is made that these demarcations allow validations and meaning in a more rigorous sense only within the framework of the individual discipline. A comprehensive perspective that would assess methodologically gained accesses as partial accesses and therefore subordinate them under an overriding principle is rejected. The question arises, how can these validations of various perspectives be mediated to each other? A view of the situation around 1800 does not merely indicate the possibility of gaining criteria that would allow the establishment of priorities for this coexistence. Yet this retrospection would also reveal that notions we apply today, which we assume as established, because they follow patterns passed on through history, are not at all discussed around 1800. Since we imagine the situation around 1800 from our contemporary perspective, we have to redefine it. Hence, new perspectives will emerge; history itself, an apparent certainty, will have to be corrected and new patterns in the genesis of developments be determined.

In this context, history has to develop its own patterns and concepts. The program of idealistic *Naturphilosophie*, emerging in Jena around 1800, was widely critiqued during the nineteenth century as a philosophy that was only at home in its own world and not in the world of science (Breidbach, "Schleidens Kritik"). The speculative phase of the inquiry of nature that characterized the situation around 1800 appeared to be no more than a phase of transition. The questions of whether and to what extent this phase can be determined have to be raised—even in Jena—in view of the multiplicity of the various scientific traditions. It is true that a line of reception can be traced—especially in the field of medicine, where a specifically Schellingian approach to *Naturphilosophie* can be explicated—and, at least in the vicinity of Jena, a specific tradition of natural philosophical argumentation can be outlined over the first decade of the nineteenth century.[6] It can also be shown that a characterization of developments in terms of a romantic natural science was not restricted to German-speaking lands.[7] The phase of a romantic conception of nature (*Naturbetrachtung*) in the provenience of Jena is a link in the chain of an overall structure to which apparently physicotheologists in England as well as Catholic currents in France can be assigned.[8]

In the context of the debate about galvanism as well as within the disciplines of chemistry or zoological systems, all European cultures were seeking analogous, speculative ways for the organization of nature, which was increasingly understood as autonomous.[9] Within this pan-European assessment, a model of development is rejected that considers speculative science as a period of transition from a non-analytical history of science to natural science. History of nature was simply a representation of the context of experience of nature, systematized under various categories of order and made accessible in the complexity of nature. According to this perspective, it was not analytical; its experience was merely asserted in a series of interconnected observations. It was only after 1800 that a status was achieved—due to the metric quantification of observations—that made an analytical observation of nature possible. It was erroneous to conclude that a romantic science of nature was going beyond the disorientation of descriptive sciences lost in all their data; it was equally incorrect to assume that it was bridging the stalemate of experimental sciences.

A close analysis reveals that speculative philosophy was deeply integrated into the efforts for a new scientific method, from where our modern conception of scientific rationality emerged. In the eighteenth century, the discourse about a purely internal determination of nature became prevalent in order to establish patterns for the living organism. At that time, it was Caspar F. Wolff who set with his *Theoria generationis* the only gradually accepted milestone in this development (Breidbach, "Zur Mechanik"). Consequently, the idea of a divinely endowed structure of the natural was to be modified. Not the particular but, at best, the program of a more and more differentiating nature was the result of divine determination. Parallel to that is a mathematical-mechanical theory of the organization of the real.

Laws existed whereby the multiplicity of the natural was organized and could become active. From the individual movements of the planets to the physiological reactions of a cognitive apparatus, the universe in particular was no longer grounded in God but could be explained as such in and of itself and through the forces that were its agents. The *L'homme de machine*, as well as the mathematician Laplace's statement to Napoleon fifty years later that the hypothesis of God no longer existed in his cosmology, define the discourse at this point in time.[10]

In his *Abhandlung über die Empfindungen* (*Traité des sensations*), Étienne Bonnot de Condillac argues that a statue, animated through sensory impressions, reveals the empowerment of a nature that could be comprehended through her agency that allowed her to come to life with the mere impression in a statue (Condillac). This idea reveals a self-confidence of a culture grounded in nature (Kondylis). It was now a matter of laws and orders that could determine these motions. Accordingly, Kant stated that natural science is only possible as mathematical discipline. The particular was no longer of interest; it was the ability to derive laws in the natural that became important for the whole. Not Carl von Linné but Newton became the hero of this kind of understanding of the inquiry of nature (Dobbs and Jacob).

Where are we situated in Jena around 1800? The groundwork for solutions and the methodological design of an analytical natural science had been articulated before 1800. At the time, it became important to render these basic forms practicable, to structure the disciplinary perspectives that had been caught in the multiplicity of individual data, and to align them with principles. This crisis of natural science would therefore be merely one of reform. On the one hand, we are confronted around 1800 with the massive political changes that were equally relevant for the sciences and for sociopolitical structures. On the other hand, we have a program for natural philosophy that explores nature to find principles that are based on the multiplicity of possible premises, and organizes sciences accordingly (Hogrebe and Hermann). It is therefore questionable whether and to what extent a simple and mono-linear development from classicism to romanticism and modernity can be postulated; this has to be questioned in view of the multiplicity of the scientific traditions in Jena around 1800. It is possible that—especially in the field of medicine—a line of reception can be drawn where a Schellingian idea of natural philosophy can be explicated; and it is possible that—at least in and around Jena—a specific tradition of natural philosophy can be traced during the first decade of the nineteenth century. However, comprehensive studies reveal that in Jena various positions were discussed in direct reference to each other (Bach and Breidbach).

Disciplines like electricity and chemistry registered a multitude of phenomena that had been systematized up to this point in a fairly loose order (Bach and Ziche). The ideal of a systematics of nature in Linné's manner was not feasible in light of this multiplicity. Furthermore, in view of Linné's natural systems, a presupposed and ultimately theologically determined interrelation of order had to be abandoned: nature had to be determined by herself (*aus sich selbst*; Stevens). Johann Friedrich Blumenbach's concept of "formative force" (*Bildungstrieb*), which comprehended the order of nature as a result of an organizing principle, did not offer a solution to the problem but drew attention to it as a massive obstacle, especially in experimental physics, where mathematics had not yet been applicable. The range of phenomena, which indeed electrified the sciences around 1800 and even persuaded the somber Georg Christoph Lichtenberg to engage in speculations, could not be formalized. Electricity, galvanism, and magnetism were new areas of inquiry where results could only be listed without the availability of criteria for quantifications of various qualities (Frercks, "Die deutsche Debatte"). A doctrine of science needed to be established where principles could be explicated that facilitated a structuring of the data. It was in this sense that Schelling understood his pure natural science (Breidbach, "Schelling und die Erfahrungswissenschaft"). As a consequence of this development, the law could be established that adequately structured a wide range of phenomena, so that possible and already recorded phenomena could be integrated. It would be an organization of knowledge that could be represented as such. But how could this be understood and rationalized? It is at this point where structural elements from aesthetic, philosophical, and everyday experiences intersect. This raises the question of how this causal interconnection could be established when it was based on self-reference.

The essays in this volume attempt—in view of the situation in Jena—to comprehend moments in the discourse about the status and the structure of sciences using the paradigm of contemporary research of nature. One of the topics is an episode in the relationship between natural science and philosophy,[11] the discussion between Schelling, the philosopher who articulated in his natural philosophy the concept of a pure natural philosophy, and the physicist Johann Ritter, whose commentaries on his experiments about the "excited muscle and nerve fiber" (*gereizte Muskel- und Nervenfaser*) Alexander von Humboldt published in his second volume with the same title. It is interesting to note that Ritter was at that point in time neither an advanced scholar nor promoted to doctor of philosophy (Weber).

It is necessary to outline more precisely the change from a descriptive inquiry of nature to analytic natural science in the nineteenth century. The change that is discussed here is defined through resignation, the decision of natural science to forgo a comprehensive explication of nature. Not the whole but the way in which further detailing of the particular is achieved is now important. Analytical natural sciences are now defined through a conscious exclusion, a rejection of the claim to know nature as a whole. Later accusations, that natural science merely constructs a canon that is only valid within its boundaries and could be called into question in view of everyday validation, miss the point. The consciousness that natural science is interested in subjective or normative sensation about the world would be more adequate than the reference to an increasing mechanization of everyday life. That natural sciences in the last few decades have indeed determined everyday experiences, their sensations, connotations, and perceptions, is another matter (Rosa).

It is equally necessary to outline the change from natural science (*Wissenschaft der Natur*)—Schelling understands this as his pure natural science—to a science of nature (*Wissenschaft von der Natur*). This means that statements describing the relations of natural phenomena have to be grounded in analytics. Consequently, a law can be established that sufficiently structures an area of phenomena in such a way that possible and even recorded phenomena can be experientially integrated. Such a description is possible without the intention to describe nature in her law-giving capacity (*Gesetzmäßigkeit*). Such a law is a statement about the inner structure of interconnected descriptions of a principle governing natural phenomena. It gains its dignity through its own validation, the statements derived about the relation of analytical methods, and the analytical construction of a grid of criteria for the selection of experiential statements. What has to be noted here is the change in the mode of inquiry. The question arises, how can the interrelations of causes that are self-referential be proven scientifically? The problem was not in the proof of the factual. Everything that could be observed was accepted in this kind of science. It was the goal to represent the complexity of the factual in a description that could render it accurately. It was the methodological problem of description to enable such a comprehensive representation—not the selection but the totality of the representation was the problem. Nature was to be comprehended in her complexity (Breidbach, *Das Organische*). How does this kind of science find orientation? How does it face the problem of losing its footing when confronted with the increasing number of details in the exploration of the particular? Classifications of areas of individual phenomena—such as Haller's schematism (*Schematismus*) of Physiology[12] —resonated in this situation. Phenomena of particulars, such as galvanism, appeared as patterns for a natural science that is now analytical. Although they existed outside of classification patterns, they allowed citing something like fundamental forces of the natural.

We have to ask, how could this science that understood specifications as expressions of basic, not yet clearly qualified forces (*qualifiziert*) find criteria that allowed the constitution of patterns of order (*Ordnungsmuster*)? The data pool of natural history was not structured. All existing systematic methods were insufficient because their parameters did not allow the integration of the new data from the areas of natural history and experimental science of nature. How could the new discoveries that no longer detailed presupposed orders but existed evidently outside of them be interpreted? A first step in an interpretation could only catalog the particular, and register and archive the marginal conditions, in which and under which they were found.

This addresses the second connection that is of interest to us. The change from natural history to natural science around 1800 was not marked with a massive methodological fissure. Even before 1790, natural science was analytical, and it remained descriptive after 1830. These modes of classifications in natural history do not deny the fact that individual fields in natural research worked with quantifications. It is known that stoichiometry (*Stöchiometrie*), the analysis of relations of measured values in the determination of substances necessary for an experiment, was already possible before the birth of modern chemistry—that is, after Lavoisier (Frercks, *Antoine Laurent Lavoisier*). It is not only the case that the phlogisticians operated accordingly in their alchemy that already worked with diversified methodological parameters (Knight, "Seeing and Believing"). Analytics is not a program of modernity. And it needs to be shown that the history of physics was written before 1800 as a history of experimentation. When Johann Carl Fischer (1763–1833) published the first history of physics as a history that organized according to systematic criteria, he conceived it as one of experimental tradition. He also showed that physics in Jena was understood as experimental science (Fischer). In this kind of physics, the phenomena are of interest. But first these had to be intuited, comprehended, and described in their classifications. Physics was the art of experiment; it was philosophy in the sense of a founding of a system of order, and it was aesthetics in the representation and perception of the results of an experiment.

NOTES

1. See Frank, *Einführung in die frühromantische Ästhetik*; Cunningham and Jardine; and Frank, "Unendliche Annäherung."

2. See Richards, *The Romantic Conception.*

3. See Bach and Breidbach.

4. See Burwick, "Achim von Arnim."

5. A romanticization that is, in retrospect, wrong simplifies the historical reality in a culpable way, especially since in the eighteenth century the attempts of

Frederic II to cultivate the "Oderbruch" were guided by a completely different economical concept of nature. See Blackbourn, *Die Eroberung der Natur*.

6. See Wiesing; Breidbach, "Jenaer Naturphilosophen."

7. See Burwick, Frederick, and Klein; Knight, *Science in the Romantic Era*.

8. See Knight and Eddy; Breidbach and Ghiselin.

9. It is evident that English natural history at the beginning of the nineteenth century incorporated deductive patterns of systematization (Richards, *Darwin and the Emergence*). The concurrent program is not a singular reflex of a reception of continental currents; on the contrary, positions found their grounding in the designs of physicotheology with English provenience, where models of a systematization were found that had been achieved through speculatively presupposed and proven rows of numbers. It needs to be pointed out that concurrent developments refer back to Newton's reception in England that became less a matter of mathematical observation of nature and more a possible interpretation of patterns of order. Scientists like Davy explicated that the concurrent fundamental conception of the natural did not remain limited to a narrow area of science (Knight, *M. Humphrey Davy*). The situation in France remains to be explored since it is especially problematic in 1800 in consideration of personnel changes after 1789. Could it be possible to understand a study such as Lamarck's *Philosophie Zoologique* as precursor of a theory of evolution or integrate it into the program of a speculative deductive structuring of nature, as it was generally articulated around 1800?

10. See Sutter; Hahn.

11. The term *natural science* is documented in Jena since 1790; see Ziche.

12. See Steinke.

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Schelling's Speculative Physics

OLAF BREIDBACH

1. Schelling's Approach and Position around 1800

The program of idealistic *Naturphilosophie,* determined to establish an order of nature (*Naturordnung)* based on speculation and to organize the empirical sciences according to this order, became a target of nineteenth-century critique that underscored the assumption that this philosophy was merely at home in its own world and not in the world of the sciences (Breidbach, "Schleidens Kritik").[1] According to this critique, empiricism and speculation appeared as two irreconcilable ideas. An analysis of the situation around 1800 reveals another picture in which speculation and empiricism existed side by side.[2]

In the 1860s, Carl Gustav Carus, president of the Leopoldina and supporter of a doctrine of nature (*Naturlehre*) that was structured according to established principles, gave a special commendation to the combative and revolutionary biologist Ernst Haeckel for his work in the comparative systematic presentation of groups of organisms—the Radiolaria (Breidbach, *Carus*). Especially in Jena, a direct line of reception can be traced—for example, in the case of Lorenz Oken—where a specifically Schellingian approach to *Naturphilosophie* was implemented in the individual sciences (Bach). Furthermore, in the first decade of the nineteenth century, a distinct philosophical tradition of internal argumentation in *Naturphilosophie* is evident in the works of Krause, Schad, and Troxler, who did not simply continue Schelling's position (Breidbach, "Jenaer Naturphilosophien"). Rather, independent developments became available. In addition, what we characterize as romantic natural science was not localized simply to German-speaking areas. This was already apparent in the borrowings and references of contemporary colleagues in the international scene, which reveal an extensive layering of cross-references.[3] The phase of a specifically romantic observation of nature with a provenance of Jena can be integrated into an overall larger structure that is congruent with the natural theology in England as well as the corresponding currents in French Catholicism.[4] This overall larger structure sought to open up analogous speculative approaches in the perception of a nature that was increasingly conceived as independent—not only in the context of a debate about Galvanism but also in disciplines such as chemistry and in zoological systems prevalent across the European cultural scene.[5]

Thus we already find before 1790 a consequently applied inductive physics, a physics that did not replicate the prescribed paths of applied mathematical procedures but attempted to feel its way experimentally.[6] In the context of electricity, magnetism, and the representation of light, we find at this point in time a differentiated experimental culture.[7] Not only individual observations but also experimental scenarios were carefully recorded. The differentiation of statements concerning experiential data was taking place in a debate on mediated experimental approaches; continuation and differentiation of individual scientific knowledge were gained in variations of descriptive experimental systems. This kind of experimental natural science thus formally corresponds exactly to what Schleiden promoted in the debate of contemporary modern natural philosophy as achievements of the newly emerging natural sciences (Breidbach, "Einleitung"). These sciences are inductive, function in an established and communicable experimental culture, and record progressions as variations and diversifications of their experimental programs. However, around 1800, sciences that adhered to this procedural method disappeared in the diversity of phenomena that became available to them.[8]

It was in this phase that Schellingian philosophy of nature gained ground. The systematic philosophical (*philosophiesystematisch*) inquiry became the answer of a speculatively schooled young scientist who responded to Fichte's radicalized position toward Kant.[9] To fill a systematic gap in methodology in the program of a Kantian philosophy by establishing a transcendental philosophy, Schelling chose as the starting point of his way of philosophizing a still undetermined domain of philosophical dispute—namely, the questions concerning the representation of our experience of nature.

This is the Schelling we encounter in 1799; but we also see him in dialogue with Johann Wilhelm Ritter, one of the prominent experimental physicists in the research of electricity (Weber, "Einleitung"). It can be shown that this dialogue was extremely fruitful for both Ritter and Schelling. In Ritter's strategy of experimentation, Schelling discovered a precise scheme that offered him the possibility of a mode of representation that demonstrated how nature was restructuring itself (Breidbach, "Schelling"). Ritter, on the other hand, discovered in Schelling's consistent explanation of nature as self-determining a template that allowed him to systematize his observations into a coherent whole. Guided by Schelling's ideas, he was able to prove in his own investigations of dynamics various stages of relations; consequently, he could associate a multitude of different representations and achieve an insightful correlation. Hence his experiments gained a systematic connection to a *Naturlehre* that he could represent in his experimental series.

Schelling attempted, as a philosopher, to provide the physicist with a model that he could not find in the multitude of phenomena available to him. He sought after principles. He was interested in the structure of the realm of nature that could represent the type of this nature through its explicatory idea of possible realisations of nature.[10] To understand and describe this structure, it is—according to Schellingian thought—necessary not only to itemize the individual parts that are treated in natural history but also to understand these parts as a realization of a general type of nature. Only then is the independent quality of nature comprehensible. Consequently, any analysis of nature cannot limit itself to entities.

An analysis of what constitutes nature could not remain with natural history, which simply narrates particulars: rather, it was necessary to explain the principle that made these entities, which were described in natural history, understandable as a realization of nature (in the sense of an absolute organism). It follows that the principle that captures this unconditional (and, in that sense, absolute) quality in the entities of the natural had to be explained. This principle cannot exceed nature because nature must always comprise this principle. Correspondingly—according to Schelling—it can only be described as a negative principle ("Erster Entwurf" 15). What nature is in itself is not accessible to transcendental philosophical thought. Philosophy can only describe the quality of nature in its own intuitive forms (*Anschauungsformen*) and it thereby obstructs the view of the essence of nature (16).[11] Nature can only be described as something that necessitates its own intuition: a principle that nature perceives as a condition of its objectification (*Vergegenständlichung*), that is, as something that represents nature not as a product—an object—but rather as productibility (*Produktibilität*), or as the possibility to be observable in objects. It is at this juncture that Ritter is able to make use of Schelling; here he gains a pattern that enables him to order his phenomena.[12] He ultimately also realized that the actual quality of his observed objects was captured in the polarity of elements and not in their identities that emerged from this polarity. From the results of his experiments, Ritter was able to describe a process and not simply a sequence of productions.[13] With the connection to Ritter, Schelling found himself in a discourse about contemporary physics. From the perspective of this particular brand of physics, nature was to be ordered according to intrinsic structural qualities. This is exactly what Schelling attempted in his philosophy of nature. In this context, he developed his speculative physics ("Einleitung").

What is this speculative physics that Schelling applied to conceptualize nature? Is this now indeed an independent description of a self that has externalized its forms of intuition (*Anschauungsformen*), a mirror that Schelling holds up to Fichte? This would be a philosophy of nature that constructs a system in which the self posits itself in freedom—according to Fichte—but also encounters itself in its gaze to the outside. Yet Schelling was looking for something else in the external, something that, from then on, also represented in theory something of the reality of our experience of nature; accordingly, the certainty that in the external we are not simply relegated to ourselves can be integrated into a philosophical discourse. Nature is not simply the other for him but always that which mediates for us the other, in which we then also know our selves and consequently find additional stability within us. That would then be a nature that, in the freedom of her unfolding, is determined by the fact that the thinking self rediscovers itself as the other. Then nature would be a mirror as the thinkable (*das Denkbare*), in which the self—usually referenced to itself (*das an sich verwiesene Ich*)—perceives itself from the outside, but not by stepping out of itself and analyzing its judgments of phenomena; on the contrary, the self finds itself in things, in what it knows to be external to itself, which can then also become an impetus for it. If such a nature is discovered, it can be recognized that her judgments are formed by something. This something can be derived in judgments that reference it; therefore, the one who judges is able to find himself again in nature. This also implies that these judgments acquire a reality—not simply that these judgments create a reality and derive nature as a possible thought but that they think of this other as something that is determined by itself. Nature is then comprehended as something that is determined in itself. Because it is possible for me to determine what is determined in itself in my thinking, I know that I have no longer lost myself in my judgments but am situated in reality.

2. Realities of Experience around 1800

That this reality—according to my modes of intuition (*Anschauungsformen*)—reduces itself to what is thinkable for me, that I describe it in categories that are at first only determined as modes of judgment (*Urteilsformen*), retreats behind this insight. I have something tangible that can guide my judgments. This is determined in itself—that means it stands for itself. It is not the reflection of a self, a simple appearance of the externalized speech of this self about itself, but rather something that is independent, something that determines itself, that the self perceives, and in which it finds itself again (Breidbach, "Über die Voraussetzungen"). Nature is accordingly not something by itself. It is the other; it is determined as something other and as such I can understand it. I am no longer alone. I stand in a world, an environment, a society, that accepts me and in which I find myself again. And I can think about this and this world; I am at home in my thinking. Such is Schelling's approach. To arrive at such prepositions, he attempts (a) to determine the thinkability (*Denkbarkeit*) of nature in a transcendental philosophical approach and then (b)—in a positive respect—to explicate this thinkable nature in the very own structure of principles that he has developed. In this respect nature can be unfolded in speculative physics (Krings).

Schelling then attempted to think of a *Naturphilosophie* in the perspective of transcendental philosophy (*transzendentalphilosophisch*). In his *Einleitung zu dem Entwurf eines Systems der Naturphilosophie oder über den Begriff der speculativen Physik und die innere Organisation eines Systems dieser Wissenschaft* (1799), he presents his argumentation.[14] To understand the layout and objective of Schellingian *Naturphilosophie* it is necessary, as a first step, to reconstruct his efforts. It will be seen that it is questionable how far this *Naturphilosophie* becomes speculative physics, and, finally, it will be necessary to discuss how far this speculative physics will be, or even can be, physics and, as such, a doctrine of empiricism (*Erfahrungslehre*).

A detailed study of Schellingian vocabulary shows that the allegedly specific articulation of his speculative physics does not take up anything other than the vocabulary and the fundamental positions of methodology of the experimental physics of his day. Polarity and exponentiation (*Potenzierung*) are by no means philosophically deduced principles but rather finely honed concepts growing out of a dialogue with experimental science.[15] This is also the case with analogical conclusions that at the time explicitly represented a procedure claimed by empirical sciences.

Schelling—and this must be noted from the beginning—moves at least linguistically at a conceptual level together with the contemporary empiricists in natural science.

Naturally, it is not easy to accept the approach of a transcendental philosophy that determines experience according to a structured cognitive mode (*Erkenntnisform*) that is gained from possibilities of intuitive modes (*Anschauungsformen*)—leaving nature as a referential ground of experimental procedure. The Kantian verdict that the objects of our experience can only be judged in accordance with our modes of intuition makes it clear that experiential connections can only have a limited claim of validity. From this perspective we treat nature in a pragmatic way. We describe it as a space of action in which we move around, and in which we outline ourselves in our actions that are related to our own intentions and in our coordination with each other. But what nature is in itself is not of interest in such a procedure. Ultimately, this is also not an object of a possible experience. This is acceptable for a science of empiricism that for its part works according to pre-given principles; it has to describe laws that structure a diversity of experience and that allow predictions to be made. As a navigator, I would be able, under certain premises gathered from the data of my registered star positions, to determine my position on the globe and formulate predictions and directives that can bring me to a certain course and to a predictable place. How far I would understand the essence of a cosmic happening is in this context uninteresting; it is only important insofar as the chosen method is efficient and reliable. The successful course of action confirms the use of such a scientific method.

It is a completely different matter when I enter those areas with my observations that I have not yet structured and for which no laws have yet been formulated but need to be organized and systematized at this point. There is no theory available here that in certain cases could lead to directives, which, in the process of my investigation, I could also falsify. In this case, I need to place the objects in relation to each other with a variety of possible attributions.[16] I thus work with these material objects, the *naturalia*, and not with abstract designations about the relation of objects that I have already systematised into specific correlations with each other.

The natural sciences around 1800 indeed knew geodesy, mechanics, and optics; they could structure their fields of study according to established principles and differentiate them further by following certain theoretical standards. On the other hand, the field of electricity was not so structured, even where the possible individual object of a hypothetical scientific theory was highly contentious. Still open for discussion were the various connections among observations. At the same time, conclusions needed to be validated on matters that had not yet been identified as objects with clearly defined references of scientific intuition. The focus of discussion is therefore the question, what is an object or thing? Insofar as it explores its objects experimentally, this phase of the analysis of nature is also concerned with the nature of things and how to obtain conclusions. Thus, questions arise: where are phenomena located in nature, and what kind of relationship to other things and appearances did they establish? Accordingly, nature itself becomes a quantity that is relevant in natural science. This is the situation in which Schelling found himself, and it is here that he developed his *Naturphilosophie*. If we consider this background, it will appear less surprising that he collaborated with a practicing experimental natural scientist—namely, Johann Wilhelm Ritter.[17]

And now the second interesting context comes into focus: the shift from natural history to natural science around 1800 was not marked by an enormous methodological paradigm shift. The study of nature (*Naturlehre*) before 1790 was also analytical, just as natural science remained descriptive after 1830.[18] The basic reason for such a differentiation in the history of science is not the fact that scientific research before 1800 did not proceed in terms of scaling and quantifying procedures. The reason is much more self-explanatory: what would the thesis be? The changes do not affect the design of experimental praxis but rather the approaches to the interpretation of what is natural. An assumption for the interesting context of speculative *Naturphilosophie* and empirical science is that in this phase *Naturphilosophie* is by no means marginal in the corresponding development but rather marks a central moment in the shift of natural history to natural science. This moment is tangible in the dialogue of the philosopher Schelling and the physicist Ritter.

This dialogue is reconstructed from the mutual appropriation of both protagonists, who worked together over months in Jena. It will be shown how, at least at one moment in time—in the period between the preparation of a proof "that a continuous galvanism is present in all processes of life" (*daß ein beständiger Galvanismus alle Lebensprozesse begleitet*, according to Ritter) and "the first sketch of a system of natural philosophy" (*dem ersten Entwurf zu einem System der Naturphilosophie*, according to Schelling)—cooperation, an exchange of ideas, and convergence had taken place. It was a moment where the boundaries between the philosophical speculation and experimentally aligned areas of observation of nature were blurred.[19] Central to this are Ritter's and Schelling's works that comprised, on the one hand, systematization of experimental science and, on the other hand, a methodology of speculative science. Both works reveal a continuing orientation for both of their sub-disciplines.

Ritter believed that he had found the key to a representation of the internal structures in nature that formed the basis of a fundamental system of forces (*Grundwirkgefüge*) with which he could explain the forms of life as forms of nature. Schelling's work was not his first attempt at a philosophy of nature but his first systematization, in which he tried to derive nature from structures he had established—that is, to develop it according to an independent system of *Naturphilosophie.*

Schelling sketches a basic form of these reactions that makes it at all possible to place such reactions side by side. Maxwell achieved something comparable at the end of the nineteenth century. His equation systems allow a wealth of areas of experience on the basis of mathematically presented structural correspondences that can be correlated with one another. These can only be found within science itself, and they can be stated in well-established internal scientific terminology.[20] This was lacking in the sciences around 1800. And it is precisely here that Schelling's philosophy, which originated in this moment in time, became indeed a doctrine of science.

3. Schelling's Order of Nature and the Philosophy of Nature as a Basis of Modern Dialectics.

With somewhat greater detail we can now examine Schelling's representation, which describes in a progression (*Stufenfolge*) of the most varied processes the phenomenon of assimilation as the basic structure of a dynamics of nature by applying modes of systematization taken from contemporary sciences.[21] Schelling attempted to grasp the aforementioned sequence of graduation (*Abfolge von Prozessstufungen*) in its necessity, which means finding the concept in which these incremental steps would be thinkable as steps in a basic process in nature. In reference to this idea, his explications that are based on the findings of contemporary sciences read at first as simple illustrations; at the same time, however, they demonstrate that his philosophy does not stand outside of the scientific debate. His concept of dynamics is deduced from the imaginative context of assimilation.[22] This is at first conceived in a very general sense as a determination of structure that can be exemplified with varying particular phenomena: it is of significance that more highly developed organisms assimilate those that are less advanced. Dynamics, in this sense, is not simply mechanics; it is a complexity of forces (*Wirkkomplexität*) in which the destruction of one organism indicates the transfer into another one. Although it is ostensibly disintegrated, it is exactly in this moment that its potentiality (*Potenz*) can be realized (Adolphi).

Nature is as such a process of "finding oneself in one's possibilities" (*ein Sich in seine Möglichkeit Finden*). Nature, according to the Schellingian approach, can therefore not simply halt its movement, liberate itself from the dynamics, and freeze. Nature is not in the product. It is in the product only insofar as the product realizes the process. Nature is therefore always alive. The underlying idea of this life of nature as assimilation, as a continuous transition, allows us, as suggested above, to describe it as a formal structure. Nature exists in her realizations and only eliminates these realizations as she surpasses them within herself. Nature places her objects in tension with each other. Nature is only characterized as nature in the opposition of her elements, an opposition that is then dissolved in a process of reciprocity (*Wechselwirkungsfunktion*). That means that nature is conceived not as a particular but necessarily as standing in relation to others. The particular exists only in this polarity. It is not a being in relation to itself (*Es ist nicht als bei sich Seiendes*). It finds its determination only in its negation as a particular. Its determination is contained in the moment of the process that identifies it indeed as a particular but does not resolve it by itself.

However, polarity itself can also not be posited. The disintegration of the process into its elements is not the process itself but rather only its marking. Duality is only knowable from the relation of both of its elements to each other—and therein polarity becomes tangible. This means that it is only realizable in its reciprocity, in the tension of its elements to one another, thus in only a condensed dimension. This third stage is only effective in the realization of duality and annihilates it only insofar as it is surpassed. Corresponding to this is that the dynamics—according to Schelling in his *System des transzendentalen Idealismus*—can only be determined in the identity of identity and non-identity, in the moment of a transition in which both remain situated in identity (383). This means that it is only realized in process. Commensurate with this would be a structure that transforms the simple stasis of duality in its dynamism; it is not external to dynamics but rather dynamics itself—and Schelling equates this with life.

In this respect, and this needs to be affirmed, Schelling's approach to the philosophy of nature gains relevance for the debate in contemporary natural science, which goes beyond a basic systematic philosophical significance. In the transcendental perspective of a philosophy of nature, a meaningful doctrine is not possible because of the fact that the relations between things determine our dealings with them and not *prima facie* the inherent characteristics of these things; furthermore, that we ultimately only encounter these things as objects of our experience, thus as entities that we arrive at with our own peculiar criteria of observation and our own determination of judgments. Natural scientists in the German-speaking world had adopted this perspective of transcendental philosophy, at least in principle, as their own.[23] Here they found the rationale with which they could explain the mathematical description of connections of order in their accessible reality. Thus they could establish that it would be preferable to have the scales and measurements of a detailed description of unique experiences or even an illustration of them. Furthermore, the numerical values that were obtained in these processes revealed the connections of order in the objective world, which could be optimized with the increasing precision gained with these measurements through induction (Heidelberger). And third, they also achieved a means by which their own progress could be measured. But all of these values are effaced if there are not acceptable standards of order according to which the objects of experience are to be structured. If not the objects of measurement but the things themselves are of interest in my experiment or in my observation, it is impossible to gain a mathematical determination of these objects' relations in a pre-established system of evidence about them.

4. "Naturphilosophie" in the Perspective of Transcendental Philosophy

What we have after Kant is a system of knowledge, an architecture of possible conclusions that we can verify for their consistency; we can also determine their internal references to each and with one another; furthermore, we can, in accordance with critical reason lay down a minimal concept of securities, determinations of validity, and presuppositions of a possible cognition.[24] That said, we still remain our selves and are not in nature, which we indeed presuppose as everyday experience but which cannot mediate as such any objective certainty. Our images of the world, our intuitions of things are primarily the projections of what is possible for us to think. What really is there—what I understand in its natural laws—is, according to Kant, non-intuitive (*nicht anschaulich*). What is then at all possible in regards to a cognition of nature?

This is where Schelling seeks to establish his philosophy of nature in the perspective of transcendental philosophy. For him a position is specified according to a philosophical system that can no longer be questioned. With this, Schelling also accommodates the empirical sciences, which, in their undifferentiated state (*Undifferenziertheit*) of systematic patterns, are not yet capable of naming their objects. Electricity, galvanism and magnetism are areas of phenomena without clear boundaries or distinctions even within their particular scientific divisions. All they could offer up to this point were certain practices and procedures in which phenomena acquired validity; these could then be described under previously established concepts proposing a framework of data that could be characterized according to the regulations of these allocated fields. Since it was impossible in the discussion between Galvani and Volta to determine conceptual designations within an area of phenomena,[25] only the methodological approach remained valid—that is, to question the phenomena themselves, to display analogies, to differentiate these analogies further, and thus to delimit the things from one another before they were determined as objects of a structural experience.

What was Schelling's methodology? From the perspective of transcendental philosophy, the discourse about nature is obviously merely the representation of our thinking about nature; accordingly, the method of transcendental philosophy can procure the fundamental conditions for thinking about nature (Breidbach, "Die Naturkonzeption"). However, it is not nature but only the thinking about nature that is determined. Moreover, nature is only understood as thinkable (*das Denkbare*) as a representation of our thinking; it is not a *sui generis* realm that transforms itself—when required—into objects. It is something other than the simple object of experience in the Kantian sense. If Schelling wants to determine this nature in itself he must think of it as something that is preconditioned by this transcendental philosophical point of view. He must find the presupposition in nature that makes it possible for us in the first place, to align feasible judgments with something. He must therefore comprehend nature in itself, in the indeterminacy of a representation of the natural that can be decided neither in categorical nor in intuitive terms.

How can this be? Schelling's approach is to represent this nature in a thought process that imagines her (*im Prozess eines sie denkenden Denkens*) and represents her as a determination of her ability to be represented (*Abbildbarkeit*): thus nature becomes what in thinking her is designed as a parameter, so that this thinking in the view of nature is also something that provides a counterpart to what is not simply itself. Consequently, in this process of self-reflection (*In-den-Blick-Nehmens*), nature has to allow herself to be determined as something that adjusts to this view, as not simply something that does just determine itself in the thought process but rather as something in which thinking inheres—furthermore, as something that allows as inherent in the thought process the possibility of a representation of thinking these thoughts (Schelling, "Einleitung" 271).

Surely this double pirouette appears somewhat intentional. But is not what leads to an intuition itself first determined in this intuition? Are the entities in which this multiplicity of phenomena can be determined as a unity comprehended through the methodology in which thinking explicates itself? That nature can be thought, that a science of it is possible, reveals it as something that we have appropriated, something that unfolds only within us and in our contact with it and what is accordingly nothing outside of us. Finally, Schelling could argue, this nature is only accessible to us as nature in her representation within ourselves. Thus, we are at the same time part of nature and determined by her. The other part of our self stages itself; it explicates itself in and to us in the forms of our intuitions as something that can be observed and comprehended. Nature as the other part of our self is accordingly what halts our thinking—is that which acts as brakes to this thinking and that which leads to boundaries that determines it and is dissolved in it. Thinking about nature is a process of contact with nature, a determination in which this autonomous thinking appears itself determined; and in this self-determination (*In-Sich-Bestimmt-Sein*) it thinks the other—namely, nature.

What this process of thinking comprehends is a demarcation. It breaks down the whole of nature into a succession of parts that need consideration (*des von ihm zu Bedenkenden*); it condenses this "other" into a succession of intuitions that are in their determination themselves a succession of the mediated. This reveals that, in all the aligning and systematization of my own determinations, something emerges that guides me (Schelling, "Einleitung" 272). This is something that appears explicit in the determination of itself; yet it identifies in these explications only boundaries of a thought process that is determined by the thinking itself. This something perhaps forces a possible unity into a discursive structure, fragments it again, and brings through this process the whole, which is made up by the parts, into focus. Nature is thus the process of an unfolding of the self (*Selbstentfaltung*), a transcendental philosophical determined thinking in which this thinking becomes productive for itself: that means that it leads to products (Schelling, "Einleitung" 290). These products exist for themselves; in these, thinking is removed as a guiding process.

These products have to be derived, determined, and measured for this way of thinking from their attributions. It only remains that thought itself is assessed by them, that it escapes through them from what actually ought to guide it: the productivity that, in the process of the natural, finds itself posited out of itself. This is Schelling's attempt to access the "other" with the methodology of transcendental philosophy.

5. Speculative Physics

In his representation, Schelling brackets what has become intuitive for him with his transcendental philosophy. He thinks the irreducible of the "other" that noticeably melts away in the reference to thinking. What is left is the description of a guiding dynamism of this thinking, which is not to be explained as such but can only be made explicit in references to thinking. According to Schelling, the possibility arises there to think these products of thinking not simply in their constitution but also in the very conditions that lead to this constitution (Schelling, "Einleitung" 294). Thus far, the idea of a productivity of nature becomes itself a condition; to think of it as a productive dimension (*Größe*) and—Schelling seems to argue as he unfolds this argument—nature is determined as a precondition of her transcendental philosophical analysis, even if she is undetermined in her productivity. But with this she is the "other"; and this "other" knows how to fit into preconceived judgments through the thinking self that is at peace with itself. In a further stage of his own "development of a system" (*Systementwicklung*), this idea leads in Schelling's *System des transzendentalen Idealismus* to a fragile balance of a reciprocal determination of differentiations in which differentiation is possible; in this difference, a nature that determines itself is also thinkable (Schelling, "Einleitung" 297–99).[26]

But there is something else of interest here. Schelling explicates in his speculative physics an established doctrine of nature that is derived deductively from a presupposed principle of a dual—or in polarity—unfolding nature. Within this polarity, an order of products is named in a graduation of processes (*Abstufung von Prozessen*) in which nature then appears self-structured. This order can be comprehended in a process of continuous differentiation that also implies a continuous diversification of the differentiating process in which the objects of nature are perceived and represented as the objects of a possible doctrine of nature (Engelhardt, "Schellings philosophische Grundlegung").

But what does this entail? Why does Schelling provide thought patterns (*Denkmuster*) in a speculative physics in which an empirical science has to be located? At the beginning—and we want to be brief—Schelling called his attempt at a doctrine of nature an experiment wherein the multiplicity of natural products was to be thought of as a necessity and—according to this idea—could be tested empirically. The clear message here is that, in the standards of a speculatively developed physics, the patterns of order are arranged in such a way that the particularities of nature can be logically positioned. If this did not fit, the doctrine of structure of this speculative physics would prove itself as inconsistent. In this realm of possible judgments, only a partial area of the factual could be made accessible. The system itself would be invalid. In an empirical challenge, it would not be the particular of a determination but rather the integration of the particular that characterizes the system of this philosophy.

6. Dynamic and Speculative Physics

Nevertheless, the reference to this speculative physics in the realm of empirical science is still unclear. Schelling differentiates between a speculative physics and a dynamic physics—to which he refers here—and in a narrower sense he breaks away from systematising physics. What is at stake here?

Schelling describes the state of scientific research in his day. According to his own criteria, he distinguishes a structured and experimentally exploratory dynamic physics that had not yet acquired clearly defined paradigms and still had to establish an order for its observations.[27] Yet a physics structured according to its own principles was in no way the most progressive doctrine of nature at that time. It was, as a matter of fact, the traditional and partly ancient paradigm of explanatory physics that teaches mechanics, optics, and physical geography according to the time-honoured principles of intuitive geometrical procedures in which things are ordered according to a Euclidean paradigm: even dynamics was to be described in terms of mechanical connections, as an analysis of a system of balance.[28] Of course, with the introduction of Newton's method of fluxions and Leibniz's integrals, a dynamic situation was then also conceivable as a sequence of complex interrelations within a minutely segmented succession. But even in these dynamics an order is retained that only allows us to determine the distances of the planets from the terrestrial sphere by means of the position of the stars in order to situate us exactly. But this fails when dynamics is to be actually described with analytical precision from merely three interacting bodies such as the sun, moon, and earth.[29]

Aside from this, the eighteenth century saw in the areas of electricity and magnetism the beginnings of an experimental demarcation of complexes of phenomena that affected the theories of optics and similarly issues of hydraulics as well as the development of thermodynamics. Therefore, around 1800, the former classical physics with its categories and strategies of thinking was in a state of flux: the new forces that experimental sciences presented could not be captured in their previous systems of ideas.

This kind of physics that proceeded inductively was highly interesting for Schelling. Ultimately, the traditional schemes used in these fields of knowledge were inadequate to structure the fields of phenomena. The presupposed orders and structures of these fields were entirely unsatisfactory. There were no new systems of classification emerging from the disciplines themselves. It can be added that for such thought patterns it was necessary to give a reason that made them valid. It was important for them to prescribe basic principles from a comprehensive perspective that put these fields of knowledge in the position to provide an order to their collection of data. Only then, in such consensus, was it possible to formulate a phenomenology of the data that were gathered experimentally and went beyond a mere sequence (*Reihung*).

In doing so, the effects of force (*Kraftwirkungen*) and dynamic situations were to be represented for physics as something that had not yet been conceived in this form within the traditional thinking of physics. In his speculative physics, Schelling could compile an appropriate schematic system for this area. He was concerned not simply with a deduction of the factual but rather with the deductive certainty of principles that allowed him to bring together the phenomena that were observed within the individual sciences, establishing a system of interrelation. This leads to the following correlation: a physics that is based on experiments sets up the apparatus for the collection of data and the completion of a multiplicity of observation that can now support—due to the insight of a principled systematisation—an interrelation of order (*Ordnungszusammenhang*) of the natural. Within this interrelation of systems, not only those areas will be linked, in which different phenomena are grouped, but also those, in which similar phenomena are classified. This also explains how a speculative physics can actually know how to distil principles that are applicable in the field of induction. Indeed, a *Naturphilosophie* emerges here to give validity to itself in the "other"; it explicates the possibility of a representation of the phenomenal in a system of classification of concrete observations that it arranges and organizes according to its criteria.

7. Thinking in Terms of Process and the Doctrine of Metamorphosis

Schelling used paradigms that can be traced back to Bonnet's approach of a graduating sequence (*Stufung*) of the natural.[30] According to this theory, the natural is not evident in the individual but in the contingent fabric of the individual as it organizes itself into the whole: nature in its diversification explicates a complex layering of reaction that realizes, in its particular types in each case, only moments of the possibility of the natural. In this sense, Schelling's concept of an *absolute organism* is understood. This absolute organism could only unfold itself in its constituting process. And so it is: the actual nature of nature is its dissolution of boundaries. Nature is, to this extent, essentially a process. But the process itself is always inherent in the finite: it is therefore never absolute in itself. It is only absolute in its whole—that is, in its infinite progressing (*Progredieren*).[31] In this it fractures *in infinite metamorphosis* (*in unendlicher Metamorphose*) the product that always points to something outside of itself (Schelling, "Einleitung" 300). This progressing cannot be represented by itself; it can only be represented in the sequence of products in which this process unfolds, which is only comprehensible in these products. The process itself is lost in the product; this must integrate itself again into the process in order to find itself in its determination. Thus the product is no longer comprehensible; it loses its form so as to show the characteristics of its nature—its productibility (*Produktibilität*). Thus the particular performs in the moment of its consolidation a type of processing; it rejects itself again immediately in the process of its consolidation and transfers itself in the progressing of the process into the metamorphosis, in which nature becomes apparent (*zur Erscheinung kommt*).

In this respect, the process is never by itself. It appears now as ordered, refers to itself in the formation of the metamorphosis as a determination, and thus to itself as nature that is determined within herself. Its designation (*Bestimmung*) is found in its determinateness (*Bestimmtheit*) as process. Determined in its absoluteness, it comes in its processuality (*Prozesshaftigkeit*) into its own and thus reaches a moment that unfolds *Naturphilosophie* in its structuredness (*Strukturiertheit*). But it is not this structure and its regularity that posits nature in itself and becomes the absolute; it is rather the dynamics that constitutes it and renders it productive. To illustrate this, Schelling defines it as a dynamic concept of structure. And Goethe, too, could understand this very simply as an interpretation of his idea of metamorphosis.[32] This nature is—entirely in Goethe's sense—a nature that unfolds itself in this process and constitutes itself in this unfolding. Nature has to be thought of as a process. I can, according to Schelling, conceptualize this process because nature can only become visible in her products yet is not exhausted in them. Finally, the particulars are thought of only as moments of the whole, custodians of that nature in whose productivity they constitute themselves. Only in the correlation of productibility (*Produktibilität*) and products does it become evident what it is they are constituted from: it is that process that determines nature—in which she is nature (*der Prozess, in dem und als der die Natur an sich ist*). Process is for us only to be comprehended in its products; these products can only be thought of as nature when they are understood as a manifestation of these processes.[33]

The products are to such an extent the result of thinking, which in the layering of nature comes to a halt; it downgrades this nature as a process that thought makes intelligible; to be in a process implies being a process and representing itself in a sequence of possible productions in their results—the products. However, the process is not necessary in these products: although the process does indeed manifest itself in them, it does not do so in a condensed way. Therefore, it does not necessarily come to a standstill. The products as moments of production reveal that something is thought in the discursiveness of the understanding that extends beyond the sequence, the shaping of the process in which nature represents itself. Because the reproduction thinks itself in the thought processes (*im Denken*) through everything consequently, it reaches the boundaries of where it can be thought as determination; at the same time, it thinks beyond these boundaries in which it is determined. According to Schelling, the limitation of thinking (*Ausbremsen des Denkens*) is condensed in the obstruction (*Hemmung*) of understanding (*Vernunft*) that unfolds discursively. At the same time, it becomes evident in this condensation that it cannot be reduced to it; it represents in a transcendental philosophy the condition of the possibility of integration into thinking that operates in the products.[34] Nature as such is also posited as a presupposition of the productivity of thinking. Nature is thus freedom in itself because it is restricted only in thinking; therefore limitation of thought exists only in regard to the simple product. This product has to be set into a system of interrelations, and dynamism has to be designed as independent.

8. Principium (Prinzipiierung) and Productivity

Schelling understood the essence of nature not merely as a structuring function of speculative thought but more as the basic texture of the natural that was also available to the individual sciences. Natural science in its most rigorous sense only became—according to Schelling—an individual science when it was in a position to articulate its particular knowledge of nature in reference to the natural principle. Thus Schelling wrote in 1799:

> Es ist also Eine Ursache, die in die Natur den ursprünglichsten Gegensatz gebracht hat, diese Ursache können wir durch die (unbekannte) Ursache des ursprünglichen Magnetismus bezeichnen. ("Erster Entwurf" 260)
>
> It is therefore One cause that introduced the most fundamental dualism in nature; we can name this cause through the (unknown) cause of the fundamental magnetism.

The modus operandi (*das Prozessuale*) of nature is thus at least a potential object of experience.

With this we rewrite a critical-transcendental philosophical doctrine of nature into a speculative doctrine of nature. This must then demonstrate to us that what is posited for us in the product can be explained by the principle of the productivity of nature, and this allows the representation of the principle difference in its naturalised form as polarity.

It can perhaps be shown precisely at this point what significance the discovery had for Schelling—that is, the proof that "a continuous galvanism accompanies the life-processes" (*ein beständiger Galvanismus die Lebensprozesse begleitet*); this is especially significant after it had become clear that with electricity and galvanism a phenomenon of physics had been discovered that allowed to bring matter into a series of tensions (*Spannungsreihe*) that expanded the possibilities of chemical analytics.[35] With this doctrine of polarity one could explain—according to Ritter—whether water was an element that could not be decomposed or whether it was a compound substance; accordingly the question arose of whether the previous systematization of chemistry needed to be updated or modified in one form or another. Nevertheless, it remained difficult for Ritter to incorporate the individual representations that were classified under the category of polarity into a systematic relation of a doctrine of nature; this could only then be successful if polarity was characterized as a fundamental determination of the productivity of nature. Consequently, nature could be comprehended in its products as the successive unfolding of this capability to produce (*Produktibilität*); and furthermore, the graduation of polarities could be derived from that. Yet this principle cannot exceed that what is constituted in it. Ultimately, nature is always comprehended according to this principle. Ritter systematized the diversity of natural phenomena under the assumption of finding nature in these differentiations. And thus everything that follows this principle is nature. Nature herself must always follow this principle. Therefore, nothing is positive that goes beyond nature. Nature can only become constituted with a negation of this principle that characterizes her. Consequently, this principle of productability (*Produktibilität*) of nature is—according to Schelling—not posited as a positive principle; it can only be described as negative and, in its inversion, as obstruction (*Hemmung*). Only that can be comprehended what prevents the potentially absolute from being absolute.

Once the universe is perceived as limited, it remains limited. It does not find access to the infinite; it is rather an impeded infinite that, insofar as it cancels its limitation in the particular, becomes again immediately impeded. Thus nature can never fulfil herself in her movement but rather progresses (*progredieren*) into the infinite. Again and again, this kind of nature finds herself anew in her limitation; lives in nothing else but within the boundaries of the absolute. That means this is not an absolute in itself but only an absolute in the act of the dissolution of boundaries. Nature, Schelling suggests, is thus not within the boundaries in which she factually finds herself—that is, in the Absolute; she is only nature in the moment of her dissolution of boundaries.

The actual nature of nature is her dissolution of boundaries.[36] Nature is, insofar it can be determined, essentially a process. The process itself is always inherent in the finite; insofar it is never absolute in itself. The process is only absolute in its claim to posit the differentiations of finding itself in difference (*die Differenzierungen eines sich in die Differenz Findens*) as a criterion of an all-encompassing systematization of natural phenomena.

Nature, according to Schelling, is the whole: nature cannot simply be reduced to a transcendental philosophical principle. In the naturalization as nature (*Naturalisation als Natur*)—thus, in this whole of nature—she can be described in a specific process. Therefore nature is an infinite progression (*Progredieren*). In this progression, process can indeed break down into its products in the particular stages of its metamorphosis; however, these products again dissolve as such during the process, bringing themselves back again into the process that constituted them in the first place. Consequently, the process then is never by itself; its whole can never be caught up in it. Thus nature also remains in a factual process that is connected to the particular, external. Her determination as absolute only finds itself in its determinateness as process. Its absoluteness can only be determined with the insight into its nature as a process (*Prozesshaftigkeit*). Not the structure and its regularity but her dynamism posits nature within herself and thus within the absolute. The process of nature is thus an explanatory process evident in intermediate steps: magnetism, electricity, and chemical processes are only to be observed here as mere partial manifestations of this fundamental dynamics of nature. The dynamics of nature is not the simple addition of the individual partial reactions. "Magnetism, electricity and chemical process are the categories of the original construction of nature" ("Magnetismus, Electricität und chemischer Prozeß sind die Kategorien der ursprünglichen Construction der Natur" [Schelling, "Einleitung" 321])

9. Polarity and Dialectics

It would lead us too far from the topic if we were to describe here in closer detail Schelling's discussion of galvanism, magnetism, and so forth. However, it can be shown that he attempted to write a new synthesis on light, oxygen, and phlogiston for not just philosophers but for the natural scientists of his day.[37] Consequently his efforts are not *Naturphilosophie* for philosophers but rather a plan for a comprehensive description of nature that was intended to establish a complete proposition of what nature is.

Schelling incorporates natural science directly in his structural debate of what nature is. He quotes Ritter in his debate on animal galvanism not only as proof of the explanatory nature of his theorem: it can be shown that Schelling and his thinking on duality and triplicity as well as the resulting concepts of the dynamics of process (*Prozessdynamik*) are taken from Ritter's work on animal electricity. He also developed the somewhat distilled formalism and placed it in a much larger context.[38] Thus Schelling did not remain within a mere reception of the natural sciences; rather, he systematized the prevalent debates concurrent to the established patterns of systematization available to him. When he interprets galvanism as an exemplification of processes in nature, he assesses the conceptual context of Ritter's physics accordingly. In this approach, the relation of determined (*Bestimmten*) and determining (*Bestimmenden*) is inverted. In his representation of this formalism of triplicity as a fundamental pattern of the natural process, Schelling characterizes the interpretation of the phenomenal as a basic pattern.[39] Even if it remains materially (*materialiter*) the pattern of thought in terms of physics, the Schellingian philosophizing turns it into a conceptual instrument that allows galvanism to be characterized as a fundamental natural process. If this pattern is accepted as valid, the particularities of the natural in their unity can be determined—according to Schelling—as nature.

Consequently, Schelling attempts to comprehend the graduation of processes (*Prozessstufungen*) in their necessity and turn them into a concept in natural philosophy. The explication of such a naturalising process is thus a deductive one in which nature—starting from the basic idea of a dynamically constituting nature—is established and clarified in her graduation with Schelling's deductive principle. Accordingly, his physics is a speculative physics, which he also presents as a doctrine of principles of an experimental physics. Eventually, speculative physics must prove itself in the transposition of its patterns of order into experimental physics that works with data that are structured by observation. Thus speculative physics transfers itself in the realm of natural science and prescribes patterns of order through which natural science then accesses its observational areas. At the same time, this speculative physics is—according to Schelling—also brought to its experimental test. A *non fingit* would render this speculative physics as false.

For Schelling, speculative physics is a dynamically constituted physics that can be transferred concurrently into a dynamic physics that can be structured through these principles. Dynamics in this sense is not mere mechanics; it is characterized through the complexity of agency that dissolves the "One" and transposes it into the "Other." Dissolution is only apparent because it is merely realized in its potential through this process. Nature is something that finds possibilities within herself (*Sich in seine Möglichkeiten Finden*). Nature exists in her realizations and only cancels them to the degree she surpasses them. Nature posits her objects in tension with each other. Nature is nature within the function of this interrelation where the duality of the elements is dissolved. That means nature is not the individual; it can only be comprehended as the particular that is necessarily in relation to another. The particular can only be grasped in this polarity. It is not something that exists by itself. Only in its negation does it become the particular; only then can it be determined. Its determination can be comprehended in the moment of process, which it engenders as the particular but which it does not conclude.

Polarity, too, cannot be posited as such. The disintegration of the process in its elements is not the process but only its demarcation. Duality itself can only be determined in the relation of its two elements to each other as duality—that is, as polarity. That means it can only realize itself in its interrelation, in the tension of its elements to each other—that is, in a condensed dimension. This third condition is only effective in the realization of the duality; it cancels it insofar as it surpasses it. Correspondingly, dynamics is—according to Schelling in his system of a transcendental idealism—only realised in the triplicity. Concurrently, the structure that transfers the mere statics of dualism into its dynamics could not be the external of this dynamics; it is dynamics itself, and this is, according to Schelling, life.

In Schelling's speculative physics, nature exists therefore only in process. But this process does not know a layering (*Schichtung*). In the stages of magnetism, electricity, and chemical process, it becomes increasingly more complex and allows thinking in terms of a declination of nature's increased complexity as a dynamic nature also in her graduations. In principle, this process is, in its reactions, only diversified in all of these stages and remains in itself singular. The principle structure of this processuality (*Prozessualität*) is therefore binary in its different stages, insofar as its constituting elements are posited in a polarity. But the process itself is the concatenation of the binary and consequently surpasses duality. Schelling names the antagonisms: attraction/repulsion, inner/outer, and plus/minus. However, it is not these products but their actions that constitute nature. Consequently, nature *is* processuality. And it diversifies itself in the graduation of its exponentiating (*potenzierend*) polarity.

Duality does not lead to dissociation but rather to structuring: it posits a graduation. The dynamism of nature therefore leads to a structural idea of dialectic. The pattern corresponds to a graduation of explicatory triplicity; it posits itself again as a discovered moment in a polarity and thus continues a process and relates, as already indicated, in its formal structure to the pattern of dialectic. The dialectic of nature is thus not a primary logical determinacy; it is not an external categorialization (*Kategoralisierung*) of nature, nor is it gained through the modes of observation in man's relation to nature. It is not master and servant but cathode and anode that constitute the basic fabric of the dialectical.[40]

Dialectics as a logical category of order develops itself in Schelling's thinking from schematism (*Schematismus*) to a structuring of the natural. Thus the conception of dialectics emerges with Schelling, not in the context of a philosophy of mind but rather in the context of a philosophy of nature. That Hegel, too, developed the moment of a dialectic of nature in his reception of the progression of thought from the discourse of the philosophy of nature as well as from the internal scientific debate is revealed in his passages on animal galvanism in the Jena writings on the philosophy of nature.[41]

10. Speculation and Empiricism.

The references between inductive science and speculation are in this respect bilateral. The thesis is that, in his writings around 1800, Schelling sought to reform the old natural history. By doing this, he had also written for scientists in this area of research. There are attempts by these researchers to establish a meta-mathematical formalism and to structure experimental procedures in science. Accordingly, mathematics is to be incorporated, but only as a moment of a description of nature, and to explicate itself. Schelling's *Allgemeine Deduction des dynamischen Processes oder der Categorieen der Physik* from 1800 already indicates this in its form—it is *philosophia more geometrico*.[42]

Schelling appropriates positions from the inductive sciences. Speculation, or more exactly, speculative philosophy of nature—Schelling suggests—does not exist outside of science (in the sense of science); it integrates the sciences and all of its results. Schelling wrote:

> Jedes Experiment ist eine Frage an die Natur, auf welche zu antworten sie gezwungen wird. Aber jede Frage enthält ein verstecktes Urtheil *a priori*; jedes Experiment, das Experiment ist, ist Prophezeiung; das Experimentiren selbst ist ein Hervorbringen der Erscheinungen. ("Einleitung" 276)

> Every experiment is only a question of nature that she is forced to answer. Yet every question implies a latent judgment *a priori*; every experiment

> that is an experiment is a prophecy; experimentation itself creates phenomena.

Schelling does not exclude the domain of the inductive from his *Naturphilosophie* but incorporates it. On the other hand, a "science of nature" that defines itself as empirical must constitute its domain of objects; it must establish criteria that clearly show in which respect and to what extent data can be transferred from the area of experiential possibilities and applied as scientific data. It has to reveal the range of questions that allow an interpretation of the experiment at hand or the results. This, according to Schelling, now has consequences for philosophy:

> Diese absolute Voraussetzung muß ihre Nothwendigkeit in sich selbst tragen, aber sie muß noch überdieß auf empirische Probe gebracht werden, denn wofern nicht aus dieser Voraussetzung alle Naturerscheinungen sich ableiten lassen, wenn im ganzen Zusammenhange der Natur eine einzige Erscheinung ist, die nicht nach jenem Princip nothwendig ist, oder ihm gar widerspricht, so ist die Voraussetzung eben dadurch schon als falsch erklärt. ("Einleitung" 277)

> This absolute presupposition has to bear its necessity within itself; furthermore, it has to be proven empirically. If all natural phenomena cannot be deduced from this presupposition, if in the whole context of nature one individual phenomenon exists that is not necessary according to this principle, or if it is contradictory, then the presupposition is already proven false.

This means that natural science is not only defined by philosophy within this framework in which the former is capable to establish its own value. Moreover, it sets with its data a benchmark for philosophy that decides about its practicability and consequently any claim to reality (*Realanspruch*).

The result of this process is not simply a certain formation of the process (*des Prozessualen*); rather, it is the process itself—the life of nature. Its externalizations are nature's manifestations. The process of nature is insofar not an abstract one, not a dimension that is determined by its form. It is realised in things. The process finds expression in the realities (*Realien*).

With that said, it will be outlined how Schelling follows the scientific argumentation of his time. He needed their statements on phenomena to be able to determine his process as a process of nature—that is, as a realized dimension. The phenomena of nature are not foreign to his philosophy. His philosophy stands in the history of nature. Consequently, his philosophy of nature is not deductive in the sense of a simple speculative inference of structural connections. According to Schelling, nature as such is not thought in her possible structure; individual sciences are not looking for a realization (*Realisierung*) of this speculatively deduced edifice. On the contrary, the diagnostic relation here is one of a dialogue.

As already mentioned, the Schellingian sketch carries with it moments of Goethe's ideas.[43] Goethe sees nature as its own realm, autonomous in itself, a world that is structured according to its own principles and that not only represents a scheme, which is reflected at first in itself, but is also itself a whole and—as such—it is form (*Gestalt*). Correspondingly, the structure of nature is to be grasped in its form (*Gestalt*). The structure of the forms (*Gestaltungen*) is the type, the sign of the whole that is articulated in the individual.[44] Goethe acknowledges within and outside of the intuition, in which he proves and systematizes things in relation to each other, that the multiplicity of the existent is to be comprehended as a faceting (*Facettierung*) of a conjoining order (*Ordnungszusammenhang*). However, Goethe does not intend to thematize a concept of structure; rather, this can be posited as real, because it can be described through the complexity of the representation of the many—that is, in the possible individuation. According to this view, the mere principium (*Prinzipiierung*) of the natural would be a contraction (*Verkürzung*), since it is not nature but the naturalization of the natural that is comprehended in these principles. The reduction of the whole to mere dynamics, the retracing to a principle that cannot be intuited, would not have been for Goethe an explanation but a contraction. For him the result would have been a mere analysis that consequently leads to dissociation and dissolution of the whole.

The question of stringency for a corresponding analytics cannot be explained in view of a conclusive representation of nature in the particular. The possible system of the natural is not unambiguous in its hierarchical references. There are alternative patterns of order. In terms of an internal natural history, these alternatives are not to be evaluated; similarly, the possible hierarchical order of Bonnet's graduation is also not at all clear. Still, nature is also to be grasped as a unity in her increments of various layers of organization of the organic and inorganic. The individual stages of development are in their sequence history; as a whole, that history represents the possibility of nature explicating herself as unity in this graduation.

Schelling understood the order of the organic somewhat differently in his 1802 sketch. According to him, the simple principles of reaction were transferred exponentially into a more encompassing structure wherein simpler reactions find a new order, and where they are determined again. The history of nature, that he shows here, only knows a direction; it is not construed.

According to Wolff, not the construction but the reconstruction of her history provides here an approach to an all-encompassing determination of the organic:

> Die historische Construktion der organischen Natur würde, in sich vollendet, die reale und objektive Seite der allgemeinen Wissenschaft derselben zum vollkommenen Ausdruck der Ideen in dieser, und dadurch mit ihr selbst wahrhaft eins machen. ("Vorlesungen" 365)
>
> The historical construction of organic nature would render—once completed in itself—the real and objective side of general science as perfect expression of ideas; it would also truly unify this and through this itself.

Indeed, his system is teleological insofar as it claims to know the highest possible in nature. This shapes itself solely according to its origin from a primordial image (*Urbild*), which is not conceived in its concrete form but only in its idea (in its own principled form) and thus as a reality that—I repeat myself—is only made accessible in the historical reconstruction: the scientist

> . . . begreife das Symbolische aller Gestalten, und daß auch in dem Besondern immer eine allgemeine Form, wie in dem Aeußern ein innerer Typus, ausgedrückt ist. Er frage nicht: wozu dient dieses oder jenes Organ? sondern: wie ist es entstanden? und zeige die reine Nothwendigkeit seiner Formation. (Schelling, "Vorlesungen" 365)
>
> . . . only comprehends the symbolic of all forms (*Gestalten*) and knows that also in the particular the general form is expressed, similar to the external that corresponds to an internal type. He may

> not ask, what is the function of this or that organ? but rather, how did this come into being? and he may show the mere necessity of its formation.

In spite of the criticism derived from his intuition for the structure of the natural process, Schelling remained in his reasoning even after 1800 still very much the representative of the typical thinking of his time. In consequence of what has been outlined with regard to empiricism, it is his effort to make available criteria of order that cannot be found through a reflection of their principled conditions. Schelling accepts the image of a hierarchical structure of nature in which a graduation represents for him a step in the unfolding of a typology of nature.[45] This graduation, which Schelling presents as a demonstration of the practicability of his philosophical approach, is explicated in the borrowing from the scientific knowledge of his day.[46] What is new in Schelling's concept is that he attempts to think of the idea of nature unfolding in a process grounded in herself: not simply in a representation of the continuities of her organization—as Goethe attempts in his *Metamorphosenlehre*—but as a basic form of the natural that gains autonomy vis-à-vis thinking. For Schelling as well as for Goethe nature exists only in process. This process was determined as one that both diversifies and unifies itself in its reactions.

11. Natural Science in its Most Rigorous Sense.

To this extent nature is presented as something that may also be grasped in its details in dynamic physics: A *Naturphilosophie* as speculative physics provides the patterns of order in which an empirical science can recover its observations and—when posited in their actual interrelations—comprehend them. Consequently, this speculative physics is not simply a deduction of a possible doctrine of nature; it explicates in its representation the necessity of an image of nature (*Naturbild*), which renders the productivity of nature experiential in its products and, in doing so, allows it to be observed as nature. This philosophy is thus the representation of what nature is for herself. It is the method for explicating nature as a quantity that structures itself according to principles. This way it becomes natural science. And it is science in the sense that knowledge about nature can be grounded in it as dimension (*Größe*). Thus it is also *natural science in the most rigorous sense of the word* (Schelling, "Einleitung" 275). Consequently, natural philosophy is a science of nature in the sense of a network of statements that supports the analytic of what needs to be described. It is necessary to find principles with which the phenomena can be ordered. Only then can laws be found in their correlations. A law would then be a statement about the inner structure of described natural phenomena. Validity is found in the applicability of such laws that, for their part, are not to be placed in an unstructured space. So it is necessary to find statements through which the analytical method finds its points of departure. At stake is the construction of a visual grid (*Sehraster*) that makes it possible to find the concepts where nature can be determined. The question of how such a self-referential grid of interrelation of science can be validated still remains. Accomplishing this requires a detailed account of how the realm of phenomena can be delineated in a descriptive science. This will become problematic for a discipline precisely at the point when it loses its previous structuring pattern.

The problem was not so much in the certainty of the factual. Everything that was to be observed was integrated in such a science. The objective was the complexity of the description. Methodical problems arose for the description where it was not evident what sort of interconnection of phenomena existed. Finally, in such a mixture, marginal conditions as such were not identifiable. The style of the descriptions can also be considered anecdotal; it may and must place different recordings side by side. Not the selection but the completeness of what is described becomes the problem: categories of order became suspect if they pretended to become more than classificatory vehicles.[47] How does science align itself in this situation once it also faces the problem to lose itself more and more in details when confronted with an increase of known particulars? Classifiers for areas of particular phenomena, like Haller's schematic of physiology, increasingly won in this situation a wide resonance. Detailed phenomena, like galvanism, appear in a *Naturlehre* that essentially proceeds analogously as a pattern of order; although they stand outside of a classificatory pattern, they seemingly claim to point to basic forces of nature.

It was important to grasp, for the first time in natural history, nature as presupposed. It was further important in this fabric of ideas to open up possibilities to comprehend the particular as exempla of something. The design of an experiment was not the goal of the project; the question was, to what extent could a more detailed way of description of interrelations be found in possible results? This was important, especially after transcendental philosophy had proven that nature could be thought of as self-determining, that she could be determined as a principled dimension, and that the principles of this determination could be deduced as a doctrine of nature. Schelling thus reveals the order of an observational science; he attempts to prescribe an order in which an interrelation of observation can be established that grows out of traditional schematics and leads to an actual intuition of nature as nature—that is, a dimension that determines itself. From that perspective, Schelling posits his natural science not outside of science, whose language—as previously mentioned—he appropriates and situates in more comprehensive interrelations. He does not prescribe how this science ought to observe, yet he determines the order in which it can organize its observational material and establish as a moment of knowledge about nature. Historically speaking, this philosophy does not stand outside of science; it stands in a direct reference to natural science that it integrates in all its particularities. When it then explicates these particularities within its system of interrelations, I systematize it. Consequently, this philosophy is not simply a speculative doctrine of nature before and outside of science. It is a doctrine that attempts to present nature as a self-determined structure; it is developed from the insight into the necessity of each and every determination of nature that requires an organization of knowledge, and it also assesses possible structures of knowledge in natural science. This *Naturphilosophie* as speculative physics is not esoteric but a doctrine of science. It does not oppose the natural scientific debates of the time. It is very much in line with natural scientists who attempt to find a methodology of structure for the recently acquired experimental interrelations in a field of physics that increasingly understands itself as experimental physics; in addition, these scientists are also looking for a methodology to provide an interrelation of science as natural science. In this respect, Schelling's philosophy is not just a systematic antipode to Fries, who was publishing around the same time[48]—despite the latter's completely different-sounding statements—and who argues from a philosophical standpoint that focuses explicitly on science and theory (*wissenschaftstheoretisch*).

But in his doctrine of natural science, Schelling operates in a phase where in an internal scientific perspective interrelations of order (*Ordnungszusammenhänge*) of the new experimentally acquired knowledge were possible; at the same time and due to the increasingly growing insight into the detail of phenomena, it was equally necessary to provide a theoretical structuring of knowledge about nature. Only ten years later, natural science would find its theoretical approach—not at least thanks to Schelling's work. Schelling's thematic shift from *Naturphilosophie* to a more comprehensive doctrine of experience takes this into account. After the end of the first decade of the nineteenth century, classificatory criteria found for the natural sciences were structured according to disciplines that included the fields of magnetism and electricity. In certain cases, it became possible to experience nature, organized in terms of polarity, as part of nature. Schelling was intimately involved in this development, which leads up to contemporary science. Later distortions of a romantic doctrine of nature à la Kern and Bernoulli respond to a situation of the now well-organized natural sciences[49]—they react around 1920 by calling it a view of nature outside of science. But it was not Schelling, notwithstanding the attempts of the Schellingians of the first generation, who declared the structure of principles of his thoughts in his philosophy of nature as the starting point of a purely deduced doctrine of nature. Indeed, they quote Schelling but do not act in the manner of Schelling's *Naturphilosophie*. Schelling brought his *Naturphilosophie* to an empirical test—not in the sense of positivism but arguably in a sense following Carnap, who later formulated his logical construction of the world as a precondition of possible argumentative stringency *pro* and not *contra* the natural sciences.

NOTES

1. See Schleiden.

2. See Engelhardt, "Naturforschung"; Richards, *Romantic Conception*; and Brain, Cohen, and Knudsen.

3. See Kanz; Wiesing 233–258; and B. Kuhn.

4. See Fénelon; Paley; and Breidbach, "Lorenz Oken and Naturphilosophie."

5. See Knight; Cunningham and Jardine; and Poggi.

6. See Stichweh.

7. See Heilbron.

8. See Breidbach and Ziche.

9. See Horstmann.

10. For Goethe's approach, see his "Erster Entwurf" and Jahn.

11. This also explains the second *Folgesatz*; see Schelling, "Erster Entwurf" 16.

12. See Breidbach and Weber.

13. See Weber, *Experimentalprogramme*.

14. See Schelling, "Einleitung zu dem Entwurf."

15. See Breidbach, *Der Analogieschluß*.

16. See Weber, *Experimentalprogramme*.

17. Richards, *Darwin*; Lenoir, "Generational Factors"; Lenoir, "Goettingen School"; Breidbach, "Naturphilosophie und Medizin."

18. See Ritter, *Beweis*; Schelling, "Erster Entwurf."

19. See Jackson.

20. See Durner, Moiso, and Jantzen.

21. See Köchy.

22. From the perspective of the scientists, the concept of natural science shortly before 1800 is used in the sense of Kantian philosophy. According to this definition, natural science characterizes a research of nature whose knowledge is assured in its structure. That means it is based on synthetic, *a priori* judgments, and thus on mathematics. Thus, natural science would not be an inductive science that could comprehend these a priori structures merely as rules of optimized communication. This is discussed and, as a result of this discussion, the idea of *a priori* certainty of natural scientific knowledge is—completely independent from Schelling's speculative approach—abandoned in the introductions of the analytical textbooks. Kant's idea of an *a priori* certainty was then understood only as the regulative of a methodical certainty of a knowledge that was differentiated according to the disciplines. The reality of nature as such was no longer a topic of discussion. The objective was to find laws in the individual disciplines that made it possible to comprehend individual natural processes. See also Hinske.

23. See Bonsiepen.

24. See Pera.

25. See Sandkaulen-Bock.

26. See Moiso.

27. See Daston.

28. See Schneider.

29. Charles de Bonnet (1720–93) formulated in his *Contemplation de la nature* and graphically explained in his *Oeuvres d'histoire naturelle et de philosophie* the idea of a natural organization represented in stages. These stages corresponded with gradations of organization in which the distinctive particulars of a collective presentation can be found. For references to Kielmeyer, see Bach, *Biologie und Philosophie*.

30. Accordingly, *Naturphilosophie* "does not have to explain the productive in nature; if it has not placed it in nature in the beginning, it will never need to bring this into nature" ("nicht das Produktive der Natur zu erklären, denn wenn sie dieses nicht ursprünglich in die Natur legt, so wird sie es nie in die Natur bringen"). This productivity of nature had already been initiated in transcendental philosophy. It is up to *Naturphilosophie* to explain "the permanent" (*das Permanente*). Schelling, "Einleitung" 289.

31. See Breidbach, *Goethes Metamorphosenlehre*.

32. See Breidbach, "Prozessualität."

33. See Breidbach, "Die Naturkonzeption Schellings."

34. See Kraai.

35. Schelling's "Erster Entwurf einer Systematik der Naturphilosophie" thus directly corresponds to Hegel's approach in his *Wissenschaft der Logik*; the forms of the autonomous unfolding of Hegelian thought correspond in their formal approach to the concepts and operations of forms of his *Jena Naturphilosophie*. Just how far these formal operations refer to Schelling's work from 1799 would be interesting to discuss further. See Breidbach, *Das Organische in Hegels Denken*; Burbidge; and Vieweg.

36. See Dürr.

37. See Ritter, *Beweis*; Schelling, "Erster Entwurf eines Systems." The interesting passages are cited and collected in Kraai's MA thesis, "Schellings Rezeption."

38. Schelling adopts Ritter's empirical results from *Beweis* 33. In 1799, Schelling used in his "Entwurf eines Systems" the idea of duplicity and triplicity. In 1800 Ritter then applied these concepts in his presentation of the

fundamental law of galvanism. See Ritter, *Beyträge* 283–84.

39. See Ottmann.

40. See Breidbach, *Das Organische in Hegels Denken.*

41. See Schelling, "Allgemeine Deduction des dynamischen Processes."

42. Only structural elements can be traced in Schelling's thoughts; to analyze the integration of ideas from the history of science is much more complicated. See Bach, *Biologie und Philosophie.*

43. See D. Kuhn and Zeller; D. Kuhn; and Engelhardt, "Natur und Geist."

44. Schelling corresponds here with Goethe's thinking. But he goes further when he presents not only the systematic pattern of the gradations but also questions their structuring; his thinking goes beyond the typological pattern of Goethe's approach. See Kanz.

45. See Durner, Moiso, and Jantzen.

46. See Stevens.

47. See Hogrebe and Herrmann.

48. See Bernoulli and Kern.

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"Art is the Expression of Eternal Being": Achim von Arnim's Poetics of Nature

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In the discourse of the interrelation and interconnection of philosophy, science, and art around 1800, Schelling, Ritter, Novalis, and Goethe occupy center stage. Although Achim of Arnim was not part of the Jena circle, his correspondence and essays on magnetism and galvanism connect him to the group (WAA 2, 3, 30, 31).[1] While Arnim mostly disagreed with Schelling's ideas about magnetism in his published writings and correspondence, his notes are evidence of an intensive preoccupation with Schelling's *Ideen zu einer Philosophie der Natur als Einleitung in das Studium der Wissenschaft* (1797)[2] and *Von der Weltseele* (1798). After his public debate with Ritter about the terminology of polarity (*Polbenennung* [WAA 2: 373–377]), he planned to dedicate his *Sammlungen zur Meteorologie* to him (WAA 2:193–205, 788; 1033–35).[3] It can be argued that Arnim's relationship with the Jena circle fluctuated between high approval and ironic distance as he positioned himself in a space where he could present his own philosophical ideas as divergent from the speculative philosophy propagated in Jena (WAA 2:37–38; 659; 278–79; 893–95).[4]

As *Naturforscher*, Arnim had gained recognition in the contemporary scientific community mainly through his essays on natural science published in Ludwig Wilhelm Gilbert's *Annalen der Physik* and in Nicolaus Scherer's *Allgemeines Journal der Chemie*. While Gilbert insisted on empirical structures and methodology, fissures in Arnim's theoretical arguments point to particular clusters of ideas that he developed more fully in his unpublished notes. In the extensive collection of manuscripts, one can trace specific concepts and philosophical reflections in which Arnim questions the classification and methodology that are implemented and practiced in each individual branch of science. While he complied with Gilbert's insistence on empirical research in his publications, he challenged the system of tightly structured empirical methodology and the separation of the disciplines[5] into subcategories in his private reflections. Here he articulates his theory of a fluid and malleable methodology, which moves "through all systems without a system" ("systemlos durch die Systeme") and reconnects all scientific branches with each other. He even goes beyond the sciences when he suggests interconnecting science and art—more specifically, all of the sciences and all of the arts.

To fully understand the complexity of Arnim's system of ideas, which he developed during the course of his studies at the universities of Halle and Göttingen, and to trace the transposition of scientific and philosophical theories into his aesthetics, the nearly one thousand pages of manuscripts have to be added to his published oeuvre. While the second volume of the *Weimarer Arnim-Ausgabe* contains all of his published writing, the third volume will include the complete collection of manuscripts and commentaries and provide access to this generally unknown body of work. As documented in his fragmented statements and his correspondence, Arnim never separated science and art. While he was a prolific scientist, he was also working on his first novel, *Hollin's Liebeleben* (1802), the tale *Aloys and Rose* (1804), the essayistic *Erzählungen von Schauspielen* (1804), and the poetic text *Ariel's Offenbarungen* (1804), revealing a wide range of experimentation with literary genres (WAA 4).[6] As outlined above, only a complete edition of all of his writings will reveal the full extent of the coexistence and interconnection of scientific and poetic theories that are the foundation of Arnim's conceptualization of his *Welterklärungsmodell*, in which he explicitly linked science and art in a complex structure of interaction between power and matter, mind and body, representation and imagination. The article at hand is an attempt to sketch again the model of his understanding of the world, gained from his work in the natural sciences, as it can be constructed from his published writings and handwritten fragments. Emphasis will be placed on the analysis of those texts in which Arnim explicitly articulates the interconnection between natural science, philosophy, and art. A close reading of the texts as well as the chronology of his poetic works will prove that Arnim never abandoned science in favor of a writer's career but always considered the sciences and the arts as interconnected and mutually engaging. To document this development, the chronology of his studies as well as his *Bildungsreise* ("educational journey"), which he undertook with his brother Carl Otto after the completion of his studies in Göttingen, will be taken into account.[7] The amorphous structure, intertextuality, and self-referentiality of Arnim's work can only be recognized within the context of the intricate structural systems that he developed in his scientific theories.

1. Immateriality as a Basic Principle of Arnim's "Specielle Kraftlehre" („Specific theory of energy") *in Versuch einer Theorie der elektrischen Erscheinungen.*

Arnim's reflections on science and poetry reveal his endeavor to represent the laws of nature as a result of the knowledge he had gained through his research about the diversity of phenomena. The endless possibilities of manifestations can only be understood through the investigation of the *how* and not the *what*. Since the causes of certain processes remain unknown, he concludes, phenomena are engendered by the interaction of bodies and energy and can only be experienced in the phase of transformation. It is important to note that he situated himself in the discourse about the materiality of matter in a minority position since he did not presuppose the necessity of any "Stoff" (*substance*) for the quantification of imponderable substances. His theory of a structure of a complex dynamic interaction of energy within and between matter was designed to transcend Kant's *Metaphysische Anfangsgründe der Naturwissenschaft* (WAA 2:6, 10). With his theory of a free repulsive force, which the eighteen-year-old presented in his 1799 publication *Versuch einer Theorie der elektrischen Erscheinung* ("Attempt at a theory of electric phenomena"), Arnim developed a system that was less concerned with the "Erscheinung" of energy than with the important question "Wie jene Urkräfte, die Repulsiv- und Attractiv-Kraft gedacht werden müssen, um die mannigfaltigen Erscheinungen der Natur hervorzubringen" ("how these primal forces, the repulsive and the attractive force, have to be imagined in order to engender the manifold phenomena in nature"; WAA 2:6). Arnim does not prioritize the phenomena that are visible or tangible through sensory perception—those forces that can be observed, described, and quantified—but rather the invisible forces that are not directly accessible to the empiricist observation. To answer this question, Arnim argues, the work of the physicist must be supplemented by the work of the physiologist because it is he who occupies himself with the most significant analysis of "wie Leben überhaupt möglich ist" ("how life is possible at all"; WAA 2:6). In a later manuscript, Arnim refers once again to his "kleine Schrift" (*short essay*), in which he had "postulated a science" that he had baptized "specielle Kraftlehre" to be able to represent and "explain" diverse natural phenomena (Arnim, "Ich habe in einer kleinen Schrift" 1^r–1^v).[8] Here he adds chemistry to physics and physiology as the third branch of science that is necessary for his theory of dynamic forces: "Diese umfasste dieser Frage gemäß den grösten Theil unsrer heutigen Physick, einen Theil der Physiologie |1^r| und die Gesetze chemischer Erscheinungen" ("this encompassed, according to the question raised before, the most comprehensive part of physics today, a part of physiology |1^r|, and the laws of chemical phenomena" [Arnim, "Ich habe in einer kleinen Schrift" 1^r–1^v]). In his previously published *Versuch einer Theorie der elektrischen Erscheinungen*, Arnim hypothetically suggested the possibility of a separation of physics and chemistry that could only take place if the laws "unter welchen Materie uns denkbar ist" ("how matter can be imagined") are defined.

> Durch die gänzliche Auflösung dieser Aufgabe würden gleichsam *a posteriori* die Gesetze ratificirt werden, unter welchen Materie uns denkbar ist; die Physik hätte dann ihre Gränzen, und griffe nicht ferner in den Wirkungskreis der Chemie ein. (WAA 2:6)

> Through the solution of this task all laws with which we imagine nature would be ratified *a posteriori*; physics had its limits and would no longer intervene into the sphere of chemistry.

A future classification of the disciplines is consequently complicated by the complexity of the "specielle Kraftlehre," which, according to Arnim, can only be solved by the interaction and interconnection of the different branches of science. In an extensive excursus, he extrapolates his ideas about the necessity of a correlation between physics, physiology, and chemistry:

> Wären alle Hypothesen erschöpft, so wäre es der Prüfung leicht, eine sicher gegründete Kraftlehre zusammen zu setzen; aber leider wie fern ist dies Ziel! wie lange werden nur Fragmente die Bahn bezeichnen und den Naturforscher in Zweifel lassen, ob die Chemie ein Theil der Physik, oder die Physik wol gar nur ein Theil der angewandten Mathematik sey. Doch hat man längst die Bemerkung gemacht, daß die Kenntnisse, welche der physischen Menschen-Erhaltung am nächsten vorarbeiten, die Seele am leichtesten zur bloßen mechanischen Beobachterin herabsetzen; es ist daher, wie ich glaube, für die Bildung des Geistes ganz vortheilhaft gewesen, die Beschäfftigung mit Chemie auch mit der Physik zu verbinden. (WAA 2:6–7)
>
> If all hypotheses were exhausted it would be easy to put together a grounded doctrine of forces; but the goal is far away! How long will only fragments mark the way and leave the naturalist in doubt, whether chemistry is part of physics or physics is part of applied mathematics. One has already remarked that knowledge that works to the advantage of the physical well-being of humankind will reduce the soul to a mechanical observer; it is advantageous for the formation of the mind to connect chemistry with physics.

At this point, Arnim integrates his theory of free movement, "systemlos durch die Systeme" ("moving through systems without a system"), which I will discuss later in more detail.

> Der Chemiker muß indessen, um ein nützlicher Chemiker zu bleiben, den Physiker während der Arbeit ganz aus den Augen verlieren, er muß, unbekümmert über ihn, Elemente annehmen und absetzen, und neue Körper daraus hervorgehen lassen, er muß bey Mischungen höchster Cohärenz, die jeder seiner Kräfte widerstehen, und bey Mischungen höchster Elasticität, die ihm unter den Händen entschlüpfen, stehen bleiben. Der Physiker weiß, was er von ihnen zu denken hat, und bleibt doch zu seiner Zeit Chemiker; der Physiolog übersieht das Ganze des großen Wechsels und forscht doch seinen kleinsten Aeußerungen nach. Ich kehre daher zu meinem Gegenstande zurück, den ich absichtlich auf einige Zeit verlassen hatte. (WAA 2:7)
>
> The chemist has, in order to remain a useful chemist, to abandon the physicist completely; he has to assume and discard elements, create new bodies out of them; he has to remain with compounds of the highest degrees of coherence that resist all forces and with compounds of highest degrees of fluidity that dissipate under his fingers. The physicist knows what to think about them and he always remains a chemist; the physiologist observes the entirety of the immense change and still explores the minutest details. I will now return to my topic that I have left behind for a short while.

By including certain chemical processes in his theory of energy, Arnim distances himself not only from Kant but also from Schelling.[9] In his paragraph "Kratzensteins Darstellung des Dualismus" ("Kratzenstein's representation of dualism"), he explicitly integrates his objections against Schelling's theories of materiality of electric matter as a "zusammengesetztes Fludium" ("a composite of fluid") and a "Produkt der Lichtmaterie" ("product of light matter"), as well as his assumption that "die beiden Elektricitäten sich durch ihre ponderablen Basen reel unterscheiden, d. h. durch das quantitätische Verhältniß ihrer ponderablen Basen zum Licht" ("both electricities are truly differentiated from one another through their ponderable bases, i.e., through the quantifiable relationship of their ponderable bases to light" [Schelling, Ideen 90–91). Arnim cites Schelling's *Ideen zu einer Philosophie der Natur als Einleitung in das Studium dieser Wissenschaft* (1797), where he argues that during the excitation of electricity, produced by the friction of bodies, no other substance is involved than the surrounding air.

> Aus der Luft aber wird der Sauerstoff nur durch Zersetzung erhalten. Wird also etwa beym Elektrisiren die Luft auch zersetzt? Aber dann müßten wir die Phänomene des Verbrennens dadurch bewirken. (Schelling, *Ideen* 57)
>
> Oxygen is gained from air through decomposition. Is air also decomposed through electricity? But then we would have to obtain phenomena of combustion through this process.

The difference between electricity and combustion is estalished through the fact that the former occurs mechanically, while the latter occurs in a chemical process.

> Wie eine chemische Zersetzung der Lebensluft die Phänomene des Verbrennens bewirkt; so bewirkt

> eine mechanische Zerlegung derselben die Phänomene der Elektricität—oder: was das Verbrennen in chemischer Rücksicht ist, ist das Elektrisiren in mechanischer Rücksicht. (Schelling, *Ideen* 57)
>
> When the chemical decomposition of oxygen produces phenomena of combustion, then the mechanical decomposition will produce phenomena of electricity—or: what combustion is in relation to chemistry, electricity is in relation to the mechanical.

In his *Von der Weltseele* (*Of the World Soul*), Schelling repeated his theory of the difference between combustion and electricity, which he had previously postulated in his *Ideen*; however, he expanded his theory and included the interconnection between warmth and light, modifying his previous principles in *Ideen* (Schelling, *Weltseele* 90–97). He argues at this point that once a body develops a certain relation to oxygen through heat (*Wärme*), it can also modify the surrounding air and turn it into electric matter. In this process, the pressure between the bodies charged by rubbing must be taken into consideration, since the air is exposed to and affected by it.

> Das Elektrisiren wäre insofern eine chemische Zerlegung der Lebensluft, weil eine Erwärmung des Körpers und eine Vergrößrung seiner Anziehungskraft gegen das Oxygene seinem elektrischen Zustand vorangeht. Es wäre eine mechanische Zerlegung, insofern das bloße Reiben dabey mitwirkt. (Schelling, *Weltseele* 94–95)
>
> Electrifying would be a chemical decomposition of oxygen because the warming of a body and an expansion of its attractive force against oxygen

> precedes its electric state. It would be a mechanical decomposition when friction is part of the process.

In contrast to Arnim, who attempted to expand the field of force and tension by postulating a hypothetical free repulsive force as part of his "specielle Kraftlehre," Schelling left the question of a third force open:

> Aber, was eigentlich die Natur und Beschaffenheit jener beyden Kräfte seye, ob sie Erscheinung Einer und derselben ursprünglichen Kraft sind, die nur durch irgend eine dritte Ursache mit sich selbst entzweyt ist, oder ob zwo ursprünglich einander entgegen strebende Kräfte, die im gewöhnlichen Zustande irgend ein Drittes gebunden hält, hier auf einmal,—man weiß nicht, wie—entfesselt und mit einander in Streit gesetzt sind? (Schelling, *Ideen* 47)[10]
>
> However, what actually is the nature and composition of those two forces, whether they are phenomena of one and the same force that is only separated by a third cause from itself, or whether two originally opposing forces, that tied a third one in their normal condition, are—no one knows how—released and are now opposing each other?

2. The "Specielle Kraftlehre" as a Model of Interaction and Integration in the Sciences

Once Arnim had developed his "specielle Kraftlehre" in his *Versuch einer Theorie der elektrischen Erscheinungen* as a complex system of the concurrences of bodies and forces, he could situate it as a foundation of his aesthetics by integrating the sciences and the arts. I have previously explored these interconnections but will briefly summarize his ideas in the context of the current discussion.[11] It is important to remember the short theoretical digression in *Versuch einer Theorie der elektrischen Erscheinungen*, which points to the junction in the empirical evidence where Arnim's philosophical theories are inserted. The *Versuch einer Theorie der elektrischen Erscheinungen* becomes a link in the chain of independent essays on electricity (WAA 2:237–63), magnetism (WAA 2:136–45), hydrology (WAA 2:193–205), and galvanism (WAA 2:371–90, 393–407), and stands in contrast to the first articles in the *Annalen der Physik*—published under Gilbert's editorship—in which Arnim reviewed and compiled research mostly from foreign journals and, in case he deviated, was reminded by Gilbert to provide empirical evidence. To explain his "specielle Kraftlehre"—the complex balance of forces as cause of motion of matter in space, which must "verschieden gedacht werden" ("be thought of as always different")—Arnim added a third force, a "freye Repulsivkraft" ("free repulsive force"), to the attractive and repulsive forces. This free repulsive force influences and changes matter, and is not restricted by its attractive force.

> . . . durch keine eigne Anziehungskraft beschränkt ist, und daher nur im Verhältnisse zu einer äußeren Anziehung an irgend einem Orte wirken kann, während der letzteren selbst die Anziehung zukömmt, und daher in allen Fällen durch sich selbst ein Gegenstand unsrer Wahrnehmung seyn kann, dagegen jene nur wahrgenommen werden kann, während sie gebunden, oder während sie aus einer Bindung in die andre übergeht. (WAA 2:7)

> . . . it is not restricted by its attractive force and can only react in relation to an external attraction in any given space while the latter (repulsive force) possesses an innate attractive force and can be the object of our perception through it own energy; the other force, however, can only be perceived when it is bound, or when it transitions from one bond to another.

Since matter and force are constrained within the boundaries of time and space, motion is transferred into a complex field of tensions so that the polar forces of attraction and repulsion, that are at work within a body, can once again bind and release each other. According to this theory, a body is then electrified when it has bound more or less free repulsive force in proportions that are defined by the relation between his own attractive force and the attractive force of the other body. If the body bound more free repulsive force in relation to the other body, then it is positive. If it bound less repulsive force, then it is negative. If it does not show any attraction to the free repulsive force, it is to be seen as isolated, which does not signify a balance of the polarized forces. This state only proves that the body is surrounded by matter whose attraction to the free repulsive force is less than its attraction to its surroundings.

The correlation between matter and force is consequently constructed as a complex system of constant exchange, in which stagnancy—a state of saturation of negative and positive forces—can only be temporary, since it will be immediately dissolved by the third force.[12] In Arnim's view, the theory of attraction between dissimilar forms of electricity is contradictory, since attraction can only work where there is something to attract. Something negative—the absence of matter—cannot be attracted and something positive—the presence of matter—can not be repelled. Arnim argues that the cause of the divergence of "leichte" ("weightless") positive bodies must reside outside of them, and in analogy, the divergence of "leichte" negative bodies must reside within them. He explains the effect of a cork-ball electrometer by observing that two equally positive electrified cork balls, isolated on silk threads, neither attract nor repel one another. The cause of the repulsion is inherent in the surrounding matter. Since the air contains two equally attractive forces, the bullets are attracted from all sides except on the side where they are touching:

> Sie entfernen sich daher, und da die anziehende Kraft der eingeschlossenen Luftschicht zwischen beiden getheilt, also schwächer ist, so würden sie sich immer entfernen, wenn nicht die allgemeine Anziehung diesem Treiben ein Ziel setzte. Die negativ elektrisirten Kugeln . . . ziehen alle Materie, die sie umringt, nur nicht eine die andre an, sie entfernen sich daher. (WAA 2:9)
>
> They withdraw from one another and, because the attractive force of the enclosed air is divided between both and is therefore weaker, they would continue to withdraw if not the general attraction would limit that process. The negatively charged balls . . . attract all surrounding matter except each other; that's why they withdraw.

If the attraction of both bullets affects the air that lies between them and the attraction of each individual bullet affects the remaining air, then, Arnim argues, the balance of force can be quantified by applying Newton's law of gravitation:

> 2) *Die Anziehung des negativ elektrischen Körpers auf den positiv elektrischen Körper ist eine*

> *unmittelbare Wirkung auf ihn durch den leeren Raum; sie vermehrt sich im umgekehrten Verhältnisse der Quadrate der Entfernungen.* (WAA 2:9)
>
> The attraction of the negatively charged body to the positively charged one is an immediate reaction because of the void; it increases in the reciprocal relationship of the squares of the distances.

In his third law, Arnim, the mathematician, can further quantify the forces.

> 3) *Jede Veränderung der Lage eines Körpers ist eine Veränderung in der Menge seiner specifisch gebundenen positiven Kraft, sie ist folglich mit größeren oder geringern elektrischen Erscheinungen verbunden.* . . die specifisch gebundene positive Kraft (ist) der Quotient der specifischen Anziehung des Körpers durch die specifische Anziehung aller gegen dieselbe. (WAA 2:10)
>
> Every change of the position of a body is a change in the quantity of its specific bound positive force; it is therefore connected to the bigger or smaller phenomena of electricity . . . the specific bound positive force [is] the ratio of the specific attraction of the body through the specific attraction of all bodies against it.

Since Arnim assumes matter as varied and, thus, as indefinite and variable, the effect of everything on everything else only happens in a neutral state of zero (WAA 2:10). This is the point where the physicist requires the assistance of the physiologist, who can link the "partiellen Lebensproceß bey den Galvanischen Erscheinungen ohne ein besonderes Fluidum abzuleiten" ("partial life process of the galvanic phenomena without deriving a particular galvanic fluid from it" [WAA 2:10]) with his system. Here Arnim stands in opposition to Alexander von Humboldt, who adhered to the theory of a galvanic and an electric fluid—the materiality of imponderable substances:

> "Diesen partiellen Lebensproceß mit einem größeren im lebenden Körper zu verketten, wird wahrscheinlich . . . der einzige unmittelbare praktische Nutzen des Galvanismus seyn"
>
> ("linking this partial life process with a larger process inside the living body, will most likely . . . be the only definite practical use of galvanism"; WAA 2:10).

In his article "Ableitung der merkwürdigsten Erscheinungen aus den dargelegten Gesetzen" ("Deduction of the most peculiar phenomena from the presented laws" [WAA 2:11-21]), Arnim, the physicist and mathematician, puts the "casuistry" of his theories to the test by applying the law of the inverse quadratic distance. However, he bears in mind that "aller Uebergang (der positiven Kraft) nie absolut frey zu nennen ist, weil er immer den Zusammenhang irgend einer Materie dabey zu überwinden hat" ("all transfer (of positive force) can never be called free, because it always has to overcome the interconnections of any given matter" [WAA 2:11]).

> Ich nenne daher allen Uebergang durch luftförmige Flüssigkeiten, nur zur Unterscheidung von dem Uebergange durch tropfbar flüssige und feste, frey. (WAA 2:11)
>
> Therefore, I call all transition through aeriform fluids, to distinguish it from the transition through fluids that drip and solid ones, free.

Before Arnim continues with the mathematical evidence of the principles of this procedure, he also introduces cultural and political associations:

> Diese Bedeutung ist gar nicht willkürlich, sondern durch Analogie mit der bürgerlichen Freyheit ganzer Völker hinlänglich bestätigt. (WAA 2:11)
>
> The concept is not arbitrary but rather sufficiently affirmed through the analogy with the civic liberty of people.

And, without any further explanation, the mathematic equations follow.

The chemist Arnim differentiates between general and elective affinity, which must be imagined as the cause of chemical transformations of all bodies. No doubt, the same force works in both cases: attraction only distinguishes itself in that it works alone in its general form and together with the repulsive force in its chemical form. The former causes approximation; the latter, decomposition or transformation of specific density of both bodies. Just as the repulsive force is the force that fills a space, the attractive force is the force that contains the repulsive force. In this balance of forces, the coherence of a body is manifested through resistance, which the restricted repulsive force uses to oppose the transformation of the body. In this process, heat plays a significant role, since it can emanate from matter without being matter. Through the addition of heat, a body is expanded— a change not in its quantity but in its quality, its chemical composition. According to this theory, heat itself is a force that works in relation to the heat capacity of a body. Arnim expands the theories represented by Kant, Franklin, Symmer, and Kratzenstein, who posit two forces that function in opposition to each other, by adding a third force that is neither bound nor unbound and can only be perceived by the rupture or splitting of the bodies. This third force exponentiates the two-dimensionality of polar opposites into a three dimensionality—the duplicity in a triplicity—in which the proportional exchange of forces and the accompanying transformations of matter take place within a defined space.

After Arnim constructed his model of a complex interaction and cooperation of bodies and forces, he could also integrate magnetism into this interconnection of electricity. In his first essay on magnets from 1799, he still differentiates between the chemical attributes of a magnet and the chemical transformation of magnetization (WAA 2:144). In the second essay about magnets from 1801, he expands the polarity from two-dimensionality into three-dimensionality and questions Schelling's geometrically constructed line of the polarity of a magnet that implies that the highest level of the attractive force would confine itself to the center of the intersecting planes (Härtl, "Amazonrepublik"). He argued against Schelling that the magnetic effects are not the result of the difference between a point and a plane but rather the consequence of simultaneous cooperation and conflict:

> [da] *die Pole wirklich nicht Punkte, sondern zwei Durchschnittsflächen sind,* die man aber natürlich in den meisten Fällen so betrachten kann, als wenn die Anziehung in einem Punkte in ihrer Mitte vereinigt sey. (WAA 2:367)[13]

> [because] poles are not points but two intersecting planes one can say that they work in most cases as if the attraction is focused on one point in the center.

With the two intersecting lines, the magnet is divided into three parts:

> . . . *zwei gleiche und einen ungleichen Theil*: also auch hier die Duplicität in der Triplicität; also

> auch hier die Erschöpfung der Combination zur Verbindung des Entgegengesetzten zu Einem, die ich schon für die Mischung der Magneten dargethan, die sich endlich auch für die nothwendige Zahl der Individuen in der magnetischen Kette nachweisen läßt. (WAA 2:367–68)
>
> . . . in two equal and one unequal part: even here exists the duplicity in the triplicity; the exhaustion of the combination in connection of the opposites into one; a process that could be observed in the composition of the magnet, a process that can now also be proven through the necessary number of individuals in the magnetic chain.

With the integration of the duplicity into the triplicity, the plane is extended to a three-dimensional space through the mathematical point of the middle, where the exchange of force, the transformation of the bodies, and the transformation of the surrounding space take place. This space is structured through a system of bodies and forces, which change not only themselves through the free exchange of qualities but also the surrounding space. Arnim also situates in the intersection of electricity and magnetism the phenomena of heat, light, and galvanism; additionally, he integrates the life process and the physiology of perception:

> Mechanische und chemische Bewegung sind sich gegenseitig in der *galvanischen Bewegung* so sehr Mittel und Zweck, daß man von dieser Seite das Leben als ein durch Herstellung des chemischen Gleichgewichts gestörtes mechanisches, und durch Herstellung des mechanischen Gleichgewichts gestörtes chemisches betrachten könnte. (WAA 2:280)

> Mechanical and chemical motion are mutual means to an end in the galvanic motion; life can be understood in this regard as a defective mechanical balance as a the result of the restitution of the chemical balance and a defective chemical balance as result of the restitution of the mechanical balance.

Galvanic motion cannot be perceived in a state of rest—only in the process of transformation, in the binding and separating of the chains. Here, Arnim repeats almost verbatim the laws he had already postulated for electricity and magnetism:

> Erschöpfung aller möglichen Combinationen entgegengesetzter Zustände zur Verbindung derselben in einem Einzelnen, ist Bedingung aller Bewegung in der Natur, also auch der galvanischen oder electrischen. Es giebt zwei einander entgegengesetzte electrische Zustände: +E und −E, und ++, +−, − − sind alle mögliche Combinationen derselben. Demnach werden zur Hervorbringung electrischer Thätigkeit zwei Klassen erfordert: eine, die eines einfachen; die zweite, die durch diese einfachen in einen zwiefachen Zustand versetzt werden kann, und von diesen zwei Klassen drei Individuen. So sehen Sie dieses von Ritter entdeckte Gesetz der galvanischen Action, welches ich auch bei genauerer Betrachtung im Magnetismus gefunden, auf eine scheinbar scherzhafte, aber doch wohl ernsthafte Art bewiesen; auch die Nothwendigkeit der Anschauung der Materie nach drei Dimensionen kann hiernach vollständig bewiesen werden. (WAA 2:283)

> Exhaustion of all possible combinations of opposite conditions in their merger into one is the condition of all motion in nature, and therefore also of galvanic or electric motion. There are two opposing electrical conditions: +E and −E, and ++, +−, − − are all possible combinations. For the production of electricity two classes are required: one, the single one, and a second, which can be transformed from the single into a dual condition; within these two classes there are three individuals. You see this law, discovered by Ritter, also acting as a law in the galvanic reaction, which can also be proven in magnetism in a kind of joking albeit serious way; the necessity of observation of matter within a three-dimensional space can be successfully proven too.

The complex phenomena are not analogous but occur in a proportional reciprocity; that also seems to prove true in regard to the integration of his theory of light into his system.

> *. . . daß alles, was Leiter in der electrischen Kette ist, Nichtleiter in der Lichtkette, und jeder Leiter in der Lichtkette, Nichtleiter in der electrischen sey.* (WAA 2:284)

> . . . that everything, which is a conductor in the electrical chain is a non-conductor in the light chain, and every conductor in the light chain is non-conductor in the electrical one.

In an entry on light in his lengthy notebook *Gedächtniskrüke*, he establishes the connection of light with electricity through a "free repulsive force."

> – – Licht freye Attractivkraft. + + strahlende Wärme freye Repulsivkraft – – u + + beyde getrennt so daß sie nicht in einem Körper verbunden Elektricität.
>
> Duplicität ist auch hier in der Triplicität zwey gleiche und ein zusammengesetztes – – Anziehung. (“Gedächtniskrüke” 130^{r})
>
> – – light free attractive force. ++ radiating heat free repulsive force – a(nd) ++ are both separated so that they are not combined in one body (–) electricity.
>
> Duplicity is inherent in the triplicity, two equal and one composite – – attraction.

In his three letters on the voltaic pile dated 1801, in which he presented his theory of chain connections and the heterogeneity of metal, Arnim was foremost concerned with the incorporation of galvanism in correlation to electricity and magnetism into the network of his system.

> *Die galvanischen Erscheinungen, die Kettenverbindungen, die Voltaische Säule gehören zu der großen Klasse von Erscheinungen, die wir unter dem Namen der electrischen begreifen, und nur in ihrer gemeinsamen Deduction wird eine Theorie als völlig geltend sich bewähren können.* (WAA 2:381)[14]
>
> The galvanic phenomena, the chain connections, and the voltaic pile belong to the large class of phenomena that we comprehend under the name of electric, and only in its mutual deduction will a theory be able to prove itself as thoroughly effective.

His manuscripts are evidence that Arnim planned a larger project, in which he wanted to devote himself to the research of meteorology, a hitherto neglected area of research, in order to include it too in his complex interconnectedness of all branches of science (Burwick, "Arnims Meteorologie-Projekt"). His "Beitrag zur Berichtigung des Streits über die ersten Gründe der Hygrologie und Hygrometrie" ("Essay on the correction of the dispute about the first causes of hydrology and hygrometry" [WAA 2:193–205]), which appeared in Annalen der Physik in 1800, is part of his preliminary scientific research, to which the manuscripts of the translation of two chapters from Saussure's *Voyages dans les Alpes* belong.[15] Among these scientific texts, the two manuscripts "Anzeige zur Vermeidung der Collision in Uebersetzung der neuern Schriften des H von Saussure: Sammlungen zur Meteorologie" ("Notification on the avoidance of collision in translation of the new writings by H. von Saussure's collections on meteorology") and "Wahrscheinlich ist dem Meteorologen alles nothwendig" ("Presumably everything is essential to the meteorologist") are different in tone and argumentation and can be grouped with the philosophically speculative fragments, in which Arnim freely associates. Since he wanted to dedicate his *Sammlungen zur Meteorologie* ("Collections on meteorology") to Ritter, the various handwritten compilations of the "Zueignung an J. W. Ritter" ("Dedication to J. W. Ritter") must be included here. In addition, the following manuscripts belong, among others, to the collection of philosophical fragments: "Der Naturforscher in die Mitte des grossen Ganzen . . . gestellt" ("The scientist, who is in the center of the universe"), "Statt ihnen etwas zu geben" ("Instead of giving them something"), "Philosophischer Standpunkt auf dem Brocken" ("Philosophical standpoint on the Brocken"), and "Verhältniß der chemischen Ausbildung zur poetischen" ("The relationship of chemical development and poetic development").

3. Arnim's Theory of the Interconnectedness of the Sciences and the Arts

Arnim's voluminous body of manuscripts documents his erudition in extensive notes from books, journals, and proceedings of the academies in Germany, Italy, England, Russia, and France. They clearly outline his project to fully understand the history and significance of the natural sciences as well as their effects on the other disciplines. There are various notes on his particular theory of history that he understood in opposition to Schelling (Arnim, "Daß dann auch der Raum"); furthermore, entries on the history of chemistry, physics, and meteorology, a bibliography of essays on the medicinal application of electricity, the history of magnetism, and his notes on the history of the phlogiston can be mentioned here (Armin, "Literatur"). It is noteworthy that Arnim did not understand the development of modern science as the paradigm shift in the sense of Kuhn, but rather as the "scientific turn"—not as the turning point *of* science but rather as the turning point *in* science.[16] That explains his integration of older theories, such as the theories of phlogiston or of hydrology.[17] In his notes on the history of humanity, natural history, and history as the manifestation of God, Arnim emphasizes again his premise of the interconnectedness of all branches of science—in other words, his understanding of knowledge as grounded in the inner connectivity of nature. In spite of the fragmented character of the texts, it becomes clear that he works with the principles of reciprocal tensions just as he had constructed them for his "specielle Kraftlehre." There is no coexistence of physics, chemistry, and meteorology but rather a complex interdependency in which the individual branches of science are determined in a reciprocal relationship.

As an example of Arnim's method of operation, his notes on the "Verhältniß der chemischen Ausbildung zur poetischen"

("The relationship of chemical development and poetic development") will be examined here more closely. First, he emphasizes that it is the history of science that shows how the coincidental is to be incorporated into a necessary interrelation of the whole, since the internal laws can be discovered in the arbitrary phenomena. These laws are, however, not strictly systematic, as is typically assumed; they rather emerge from the relation to inner and outer influences and factors and through this, remain mutable.

> Die Geschichte einer Wissenschaft sucht das scheinbar Zufällige ihrer Entwickelung in seinem nothwendigen Zusammenhange zu zeigen, sie sucht auf wie jeder einzelne Schritt zu dieser Entwickelung mitwirkte. So betrachtet auch der Chemiker seine Wissenschaft, denn das soll die Chemie ihm werden und keine systematische Kunst aber der Mensch denkt noch mehr, er möchte auch gerne wissen in welchem Verhältnisse stand sie zu dieser ganzen Ausbildung und wie wurde sie durch diese bestimmt und warum waren jene Hindernisse, die ihr im Wege standen zur Ausbildung des Ganzen nothwendig und dies wünschte ich in einem kurzen Ueberblicke zu zeigen. (Arnim, "Verhältniß der chemischen Ausbildung")[18]

> The history of science is trying to prove the correlation of apparently accidental occurrences in a causal connection; it attempts to show how each step is necessary in this development. That's why the chemist understands his science, because chemistry is supposed to become like that and not a systematic science; but man thinks further and wants to know in what kind of relationship it

> stands to the formation of the whole, and how was it determined and why were the obstacles, that were standing in its way, necessary for this development, and I wanted to show this in my survey.

To illustrate that mutual permeation and interconnectedness goes beyond the disciplines in the sciences, Arnim suggests a field of tensions between chemistry and poetry, in which the different methods of perception and representation can be observed. While the method of scientific research is analysis and separation, the representation of the individual as a whole lies in the creative imagination of the poet. Because both views of nature stand in opposition to each other, the conditions are created to promote the common goal of the progress of humankind.

> Daß der Chemiker die Natur anders ansieht als der Dichter im weitesten Sinne des Worts bedarf keiner Erinnerung. Jenem erstirbt das Einzelne weil er es |1r| vom Ganzen getrennt und das Ganze weil er es vereinzelt hat, diesem lebt es stets in abwechselnder Gestalt, Chemie wird daher durch Poesie da wo sie es ganz ist behindert sowie sie diese wiederum beschränkt. Aber es ist nothwendige Forderung bey einer Kenntniß die dem Besten des ganzen Menschengeschlechts gewidmet daß sie dem ganzen mitgetheilt werde und dies wird der einzige Zweck seyn, den alle ihre Verändrungen haben müssen, die Poesie wird ihr daher in aller Rücksicht entgegen seyn sowohl im Entstehen wie in ihrer Verbreitung. (Arnim, "Verhältniß der chemischen Ausbildung")

> That the chemist sees nature differently than the poet in its widest sense is not worth mentioning.

> The chemist loses sight of the singular because he separates it from the whole; for the poet it is alive in every shape; chemistry is therefore impeded by poetry when it is only chemistry and poetry is likewise obstructed. But it is a necessary demand with the knowledge that is dedicated to the best of humankind that it is disclosed to the entire world and this is the only purpose for all change; poetry will be in opposition in every direction in its creation as well as in its dissemination.

The intrinsic poetry of nature remains pure and can be perceived in natural phenomena such as the ethereal sounds evoked by the rays of the sun at the Colossi of Memnon in Egypt. In contrast, chemistry is defined through its purpose and its usefulness. Both chemistry and poetry are not assigned to mutually exclusive systems; rather, they fulfill their purpose within their own complex relationship. While chemistry remains persistent in its goal of constructing a "complete scientific system," it is poetry that can connect the external with the internal in a "complete organic system."

> Die poetische Ansicht der Natur findet in dem ersten Strahle der Sonne der in Memnons kalter Brust Harmonien entzündet ihren Ursprung sie hat keinen Zweck also brauch[t] sie keine Veranlassung, die |1^{v}| Chemie will die Materie zum Gebrauche der Menschen veredeln, das setzt einen Gebrauch und Bedürfnisse voraus. Jene schützte sich durch den Trieb diese durch das nothwendige Bedürfniß In diesem Kampfe worin wir bald beyde Beschauungsarten der Natur sehen bleiben sie nur so lange bis der Naturforscher durch vollständigere Entwickelung des Einzelnen wieder

> ein Ganzes daraus zu bilden versuchte. Freylich wird diese Bildung eines vollständigen Systems lange vielleicht immer nur Annäherung seyn während die Dichtkunst ein in sich vollständiges organisches System das Aeussere mit dem Innern [uns darlegt] aber jene Trennung war nothwendig also ist diese Verbindung erfreulich und wenn jenes das verlorne Paradies genannt werden kann so ist dieses das wieder gewonnene und gleichsam eine zweyte Dichtung.|2^r| (Arnim, "Verhältniß der chemischen Ausbildung")
>
> The poetic contemplation of nature finds its origin in the first ray of the sun that stirs harmonies in Memnon's cold heart; it does not have a purpose and does not need a motive; chemistry wants to refine matter for human use that presupposes utility and needs. The former protected itself through passion, the latter through need. In this struggle, in which we see both contemplations of nature engaged, they will remain until the naturalist can forge a complete unity out of the development of the indviduals. It is true, the formation of a more complete system will remain an approximation while poetry can lay out for us a complete organic system by integrating the external into the internal; this separation was necessary and the unification is joyful, and, if the former can be called the lost paradiese, the latter can be called paradise regained, so to speak, a second poetry.

Separations and reconnections are not simply analysis and synthesis—dissolution and reconstitution of the original substance—but rather resolution and reorganization of matter and force, which ultimately cannot exhaust itself because of the possibility of infinite numbers of combinations. The principles of chemical properties are linked to physics when Arnim talks about limitations and counter-reaction, that is, the cohesion of bodies, attraction, and repulsion.

> Die poetische Ansicht der Natur begrenzt also die naturforschende und wirkt ihr entgegen und doch macht sie das was wir eigentlich Naturlehre nennen erst möglich. Aus diesem Widerstreite erklärt sich der Einfluß der Religion, den ich früher entwickelt habe, denn nur in sofern sie Poesie war wirkte sie ihr entgegen und nur in sofern sie es durch die Reformation seit Luther aufhörte legte sich dieser Anstoß. Welche Hindernisse bis dahin zu über winden waren lehrt die Uebersicht der Verbreitung. |2^v| (Arnim, "Verhältniß der chemischen Ausbildung")

> The poetic contemplation of nature limits the one practiced by the naturalist; it opposes it, yet it makes what we call the study of nature possible. The influence of religion can be derived from this struggle because it has its origin in poetry; it was opposing it yet it ceased to do so after Luther and the reformation. A synopsis of its propagation reveals what kind of obstacles had to be overcome.

Another example is the excerpt of a manuscript entitled "Der Naturforscher, in die Mitte des grossen Ganzen . . . gestellt" ("The scientist, who is in the center of the universe"). Here Arnim argues that it is the scientist's challenge to unite the different branches into a unifying whole. Arnim stresses again that the scientific method itself makes it difficult to fully understand nature.

> Der Naturforscher, in die Mitte des grossen Ganzen frey strebender Thätigkeiten gestellt übt das grausame Geschäft einzelne Momente herauszuheben; das Einzelne erstirbt unter seiner Arbeit, weil er es aus dem Totalverhältnisse riß, das Ganze, weil er es in das Einzelne zerlegte. Wozu dies unheilige Unternehmen, wozu dieser Angriff auf das Erhabenste, wenn er nicht nothwendig Gesetz des Ganzen wäre, wenn nicht eben in diesem Trennen und Einzeln und durch dieselbe jene Thätigkeit bestände. Auch das muß uns hiebey gewiß bleiben, die Rückkehr werde sich uns nicht verschliessen und durch angestrengte Kraft lasse sich das Einzelne wieder zum Ganzen verbinden durch Entwicklung ihrer Nothwendigkeit und ihrer Gesetze. |1r| (Arnim, "Naturforscher")
>
> The naturalist, positioned in the center of the great system of freely striving activities exercises the cruel business to emphasize single moments; the singular dies away in his work because he has torn it away from its totality; the whole, too, dies away because he has divided it into fragments. Why this unsacred business, why this attack on the sublime, if it were not the necessary law of the totality, if agency was not derived through this separation of the singular. It has to remain certain; a return will be possible and with great struggle the singular will be reconnected to the whole through the development of its necessity and its laws.

Arnim's notion of experience, which he articulates in contrast to Kant and Schelling, cannot be discussed in detail within the context of this essay. Mentioned here is only the longer manuscript, the twenty-two-page fragment 1: "Statt ihnen etwas zu geben." A compilation of his theories in nineteen points and marginalia, the fragment is one of the most comprehensive theoretical texts in his body of scientific manuscripts and provides an insight into the structures of his system. The more speculative manuscripts belong to this convolute of the dedication to Ritter and were intended to be included in the preface to his *Sammlungen zur Meteorologie* ("Collections on Meteorology"); they are written more hastily and are difficult to edit. Earlier versions can be dated back to his university years around 1800–1802, since Arnim refers to his other manuscripts and his plan to write a natural history.[19] A later cleaner copy can be dated to 1809–1811, when he made the decision to publicize a selection of his scientific writings (Burwick, "Arnims Meteorologie-Projekt" 136; WAA 2:468).[20] For further discussions on the individual essays and for quotations, I refer to my earlier publications; in this essay, I will explore Anim's structural fabric of interconnectedness that also includes meteorology, a new field of research at the end of the eighteenth century.

Arnim was mostly concerned to close the gap on scientific research about meteorological procedures and knowledge gained from empirical data. He translated two chapters from Saussure's *Voyages dans les Alpes* and added his own barometer and thermometer measurements, which he had either conducted himself or compiled from different sources. Furthermore, he was interested in meteorological phenomena, since they seemed to follow arbitrary and coincidental laws and did not conform to a specific pattern. He argued that the space for experimentation and observation expands into the universe where human experience can no longer provide sufficient data. Based on this limitation, the meteorologist is the only scientist who is allowed to speculate and posit hypotheses that exceed empiricism; he is also charged with the task of developing new methods of inquiry. The point is to research individual procedures that can be significant in their effect for the universal context of natural phenomena, even if their physical laws are not yet known.

> Denn was ist die Meteorologie uns jezt; ich fordre kühn die Physiker heraus, die Einheit der Bewegung unsrer Atmosphäre wie des Sternenhimmels aus dem, was wir bisher davon erfahren, mir zu bestimmen, den Regen wie die Sonnenfinsterniß vorherzusagen und doch kann auch hier der Zufall regellos nicht walten und diese Regeln müssen auch hier einst begriffen werden. (Das wäre dann echt praktisch, ganz in dem Sinne des grossen Rufs der Zeit, wäre es dann noch popular, so wäre es vollständig denn wie viel echt praktischen Zeitvertreib stört die veränderliche Laune |2^v| der Witterung. (Arnim, "Wahrscheinlich ist dem Meteorologen")
>
> What is meteorology for us now; I challenge the physicists to determine with the knowledge we possess at this particular moment the unity of motion of our atmosphere and the starry skies; to predict the rain and solar eclipse; and yet, it can not be accidental and arbitrary, and the rules have to be understood in the future. (It would be quite practical in the sense of the great challenge of our time; if it were still popular it would be complete since a lot of pleasure is spoiled because of the whims of weather.)

In this context, history is an infinite "Wechseln und Werden" (exchange/changing and becoming), a perpetual process of metamorphosis that produces changes in endless combinations.

. . . wir sehen ein daß die Erde wie jedes im Wechseln und Werden noch eben so begriffen ist wie sie es in der frühesten Zeit war, daß nun nur die Gesetze dieser Verändrung, das Integral dieser Functionen und nichts mehr aufzufinden sey. Und dieses Princip wird wenn mich nicht alles täuscht allein in der bisherigen Meteorologie sich zeigen. Ists nicht in der Atmosphäre, wo jede Verändrung |2^r| der Erde Vulkanische Ausbrüche und Erdbeben sich vorbereitet, durch deren Einwirkung noch jezt Gebürge zertrümmern und entstehen, Aber welches ist das Princip aller dieser Verändrungen. Ich will einen Versuch wagen aber sicher ist es nicht der letzte, genug wenn er nur über eine allgemeine Beziehung uns weiter aufklärte. Ich sagte ohne einen Beweis zu geben Erschöpfung aller Combination zur Verbindung des Entgegengesetzten zu einem sey das Gesetz aller Veränderungen. (Armin, "Aber ist es nicht aufmunternd")

. . . we realize that earth is like everything else still in the process of change and development, exactly like it was in the earliest times; now only the laws of these changes, the integral of these functions and nothing else have to be discovered. And this principle will become evident – if I am not mistaken – solely in meteorology. Is it not the atmosphere where every change in the earth, volcanic eruptions and earthquakes, is prepared by which even now mountains are destroyed and created? But what is the principle of all change. I want to venture to answer this question but certainly this is not the last answer, enough, if it just

> explains a very general relationship. I say, without offering any proof, that exhaustion of all combinations of the connection of opposite forces into a total unity is the law of all change.

Arnim argues that empiricism can only create a rigid system and instead defines the method of scientific research as a "systemlos durch alle Systeme Fortbewegen." These forms of free motion are analogous to the motions of the free repulsive force, which, by connecting the disciplines in the sciences, establishes the natural laws that are grounded in the complexity of inter-relationships. In 1809–1811, he still remembers his methodology, with which he had compiled his *Sammlungen zur Meteorologie* ("Collections of meteorology"):

> Meine Arbeiten, die ich ohne Aufmunterung gegen mancherley Hindernisse und fremdartige Beschäftigungen bis zum Schlusse meines Studentenlebens durchgeführt hatte, wurden in einer Zeit durch eine Reise in den Hauptländern Europas unterbrochen, wo ich in Untersuchungen über die Perioden und nothwendigen Zeit, durch die ich der Meteorologie Sicherheit zu geben hoffte, so weitläuftig sammelte, die mögliche Combinazion zu erschöpfen und systemlos |1$^{\text{v}}$| durch alle Systeme mich fortbewegte, daß manche dieser Papiere mir jezt mehr Mühe machen, zum Verstehen als damals beym Verfassen . . . (Armin, "Zueignung")

> My studies, which I have conducted without any encouragement and against many an obstacle up to the end of my university years, were interrupted in a time of traveling through Europe; through my research into the necessary periods,

> I had attempted at this time to gain knowledge and certainty about meteorology; I had collected much material to exhaust all possible combinations and had moved through all systems without a system, that it is more difficult for me now to understand my notes than it was during the time of investigation . . .

His dedication to Ritter and the manuscripts that belong to this convolute are distinguished from Arnim's published essays through their style that unquestionably approaches a "stream of consciousness." There is no systematically structured argumentation but rather a flow and drifting of thoughts, ideas, and associations. Through the almost poetic language, these writings can be placed exactly at the junction where poetry is transitioning into natural science.

> Aber nicht die Bewegung der Sterne allein, alles was sich regt und strebt in der Natur, sey es organisch oder unorganisch alles hat seinen Grund in der Vergangenheit seine Folge in der Zukunft, wer der Grund weiß hat, die Folgen und bis zu diesem Punkte ist alles der Natur Wunder. Diese kühne Fordrung meiner Freyheit, alle Verändrungen am Himmel, allen Wechsel auf der Erde aus einem bestimmten Erfahrungspunkte in Gegenwart und Zukunft zu entwickeln, den Regen wie Sonnenfinsternisse das Bilden der Gebirge wie die Wiederkehr der Cometen ist, ich gestehe es, wie jede astronomische Aufgabe durchaus eine endliche Auflösung einer unendligen Aufgabe, aber eben indem in jeder Auflösung wieder der [weitere Cristall liegt] aber das ist schon genug, genug zur Befriedigung |2^{r}| jenes Bedürfnisses, auch in der

einzelnen die ganze Unendlichkeit der Natur aufzufinden zur Untersuchung führte. Was ich hier zu geben wünsche sind Beobachtungen zu diesem Zwecke besonders wichtig und wechselsweis vereinigt bald unter verschiedenen Gesichtspunkten. So nähert sich mit jedem Schritte die Theorie der ganzen Erfahrungswelt, frey bewegen wir uns systemlos durch Systeme, wir sehen worauf der Weg uns führt befragen die Erfahrung um die Folgen, sehn wir im Falschen enden, was uns Wahrheit schien, worauf sie uns geführt, das ist doch wahr, die Theorie vergeht doch fest ist das gefundene Gesetz, der Kreis des Wissens dreht sich wandelnd um und jeder Schritt zeigt uns die Welt von andern Seiten. Was hier gesucht wird ist weder innere noch äussere Naturgeschichte, es ist die Geschichte der Natur. (Armin, "Zueignung")[21]

Not only the motion of the stars but everything that moves and strives in nature, be it organic or inorganic, has its origin in the past, his destiny in the future; those who know the origin know the consequence and up to this point everything in nature is a miracle of nature. This daring demand of my freedom, to develop all transformations in the heavens, all changes on earth from a specific point of experience in the present and the past, rain and solar eclypses, creation of mounatins and the return of comets, is, I admit, like every astronomic task a finite solution of an infinite question. But because in every answer is another [crystal], it is enough, enough to satisfy the need, to find and explore in the singular the infinity of nature.

> What I wished to offer are observations that are especially important and can be alternately combined under various perspectives. With every step the theory of our experienced world gets closer; we move freely through all systems; we see where our path leads us, we ask our experiences for the outcome; if we err in what we considered the truth, then it is true; theories pass but firm is the law; the circle of knowledge is turning in eternal change and every step shows us the world in a new perspective. What we are looking for is neither the inner nor the external history of the earth . . . but the history of nature.

Later records and publications clearly show that Arnim was no longer concerned about scientific experiences alone; he now explored ways of knowing about the interrelationships: the relation of force and matter in the general context of man and nature.

4. Arnim's Theory of the Limits of Scientific Knowledge about the World

The draft of a letter to Stephan August Winkelmann opens with Arnim's acknowledgment of Winkelmann's positive reception of his first essay on magnetism. Winkelmann had recognized Arnim and Ritter in *Einleitung in die dynamische Physiologie* (*Introduction to Dynamic Physiology*) for proving that the specific weight and the degree of coherence of a body do not coincide (22). He mentioned Arnim once again in his explications about the "Princip der Gestaltung" ("Principle of formation") of the earth's poles. He specifically praised his explanation of the magnetic effect, which Arnim understood in opposition to the chemical properties of the poles (WAA 31:236–38; Winkelmann, *Einleitung* 25). While Arnim experimented with ideas of triangulation, Winkelmann constructed his binary system of physiology in *Einleitung in die dynamische Physiologie* from the concept of an all-inherent dualism and developed the notion of metamorphosis into a central formative principle in nature. In his system, the eye became the "consummation of metamorphosis" and life the "finest sense," which neutralized the antagonism of the negative as much as possible.[22] In the draft of his letter, Arnim goes beyond Winkelmann by removing the physiology of perception that Winkelmann had confined to the capabilities of the human senses and transposing it into a liminal realm of experience in which metamorphosis is augmented once again.

> Das Princip aller Bildung heist in meinem System Ahndung, die Metamorphose wäre ohne dieses Princip nicht vorhanden, eben sowenig ihr Gesetz die Combination, ohne diese Ahndung hätten wir weiter nichts gewiß als was uns Kant's metaphysische Anfangsgründe der Naturwissenschaft geben, aus welchem Standpunkte ich mich durch mein erstes Buch die Theorie der elektrischen Erscheinungen zu befreien suchte, weil mich diese Tiefe ohne Grund, diese unendlige Nichtigkeit schreckte. (WAA 31:237)[23]

> The principle of all formation is in my system presentiment; metamorphosis would not be possible without this principle; and neither would be the law of combination; without this presentiment we would have nothing else but what Kant gave us in his metaphysische Anfangsgründe der Naturwissenschaft, a premise from which I tried to distance

> myself in my first book, the "Theorie of electrical phenomena," because this bottomless depth, this infinite nothingness frightened me.

With his attempt to connect the empirical reality with the world that cannot be experienced through the human mind, Arnim constructed a four-dimensional realm whose structure required the construction of a new space and time that transcends three-dimensionality. He explained this in a notation in his diary from 1803–04:

> Daß dann auch der Raum mehr als drey Dimensionen haben muß und die Zeit mehr Evoluzionen als Vergangenheit Gegenwart und Zukunft und das Denken außer dem Subjekt und Objekt noch das dritte kennen muß, dem wir uns jezt nur unendlich |96| nähern ist wohl gewiß, also kann dann wohl in denselbem Raume den wir jezt bewohnen in derselben Zeit noch eine andre Welt seyn, so wie unendlich viele Flächen im Matematischen Sinn noch keine Dicke bekommen und also nichts weiter wie eine Anschauung von dem Körper bleiben, von dem wir doch gar nichts wissen würden, wenn wir nicht verständen was Dicke. (Arnim, "Taschenbuch" 96-97)

> It is certain that the space, which we can only approach in eternity, has to have more than three dimensions and the time more evolutions than past, present and future, and thought must know a third entity besides subject and object. That's why we can assume that in the space we inhabit and the time we live there is another world; an infinite amount of planes do not become thickness in

> the mathematical sense and remain an idea about the actual object of which we would not even know anything unless we understood what thickness means.

The presentiment of such a higher world, which remains closed to the human imagination and the modes of representation in every day life, is, according to Arnim, only possible in the liminality of the transition from life to death—more specifically, in the hours of dying.

> Dieses löst das Problem der Evoluzion der Welten auf, der sterbende Körper erhält einer seits eine neue Dimension in seinem einen Pole, so versinkt da der andre Pol nach allen bisherigen Dimensionen, er zerstäubt und zerduftet. Er bekommt eine neue |97| Zeitevoluzion, unsre Perioden des Blutumlaufs, der Schlafzeit, der Reproduction des Wachsens Blühens und Sinkens haben sich in einer höheren aufgelöst. (Arnim, "Taschenbuch 97-98)

> This solves the problem of the evolution of the worlds; the dying body experiences a new dimension in one of its poles because the other poles sink into all the familiar dimensions; it scatters and dissolves. It gains a new revolution of time; our periods of blood circulation, sleep, and reproduction in growth, bloom and decay have dissolved into something higher.

Arnim argues that the scientific endeavors to represent phenomena that cannot be experienced or calculated in quantifiable laws, have to remain futile; it is the arts that can give form to the interconnection and cooperation in moments of "presentiment." Only the artist's highly refined physiology of the senses as well as the body, which in performance opens itself up to highly intensified sense perceptions, are significant; through the interconnection of all modes of sensory perception, the arts can represent what each individual art form cannot portray.

> Durch die Kunst läst sich dieses ahnden, sie zeigt wie in der Mahlerey zwey Dimensionen alles geben kann, was dreye sonst dem Auge darbiethen, Musik und Bildhauerkunst geben den todten Stoff den Lebensausdruck des Lebenden, jene den flüssigen diese den festen (jene ist die Bildhauerey des Flüssigen [(]also der Liebe so wie diese Bildhauerey der Ehre) Es scheint als wenn das Vergnügen der Baukunst auch nur darin liegt das in den Verhältnissen einer Dimension der Linie als Repräsentant der übrigen auch jene erinnert wird, wie bey den Zeichnungen von Umrissen denn die Anwendung der Farben oder der Bildhauerey bey jener ist ganz unabhängig, so wie bey dieser der hinzugefügte Schatten und Licht, welches wiederum zeigt wie grössere Verhältnisse durch kleinere ausgedrückt werden können. Der Tanz endlig vollendet in allen seinen Zweigen das Kunstwerk, in seinem Gegensatze zur Dichtkunst, jener auswärts, diese inwärts sammelt eine Welt von Empfindung des Räumligen wie des Zeitligen diese in einem Punkte jene in einem Augenblick. Wozu nun die übrigen, wenn diese uns alles jenes darstellen können. (Arnim, "Taschenbuch" 97–99)
>
> This can be experienced intuitively through art; it shows how painting can render in two dimensions everything that the eye perceives in three

> dimensions; music and sculpture endow dead matter with the expression of life; the former the fluid, the latter the solid (the former is the sculpture of the fluid—that is love—like this is the sculpture of honor). It appears as if the pleasure of architecture lies in the ability to represent in the relation of the one dimension of the line all the other dimensions; in drawings it is the contours, since the application of color or sculpture is independent; likewise, the addition of shadow and light can express larger dimensions in a smaller scale.

In a fragment from the year 1808, Arnim once again reflects on the structural fabric of four-dimensionality, which he had already articulated earlier in his notebook. New is his idea that both the three- and the four-dimensional realm can coexist in a complex structural network. In this structure, man is integrated with body and mind; however, he can only divine this higher world through his "imaginary pole"—through strata that are stored as memories in the mental and the subconscious domains. Arnim repeats almost verbatim his thoughts.

> Daß dann auch der Raum mehr als drey Dimensionen haben muß und die Zeit mehr Evoluzionen als Vergangenheit, Gegenwart und Zukunft und das Denken ausser dem Objekt und Subjekt noch ein drittes kennen muß ist wohl gewiß. Nähern wir uns vielleicht dem? In demselben Raume, den wir jezt erfüllen kann also vielleicht ein andrer höherer Raum coexistiren für höhere Anschauung die Form, dasselbe mit der Zeit. Berühren können wir den ebensowenig |4^{v}| als tausend mathematische Flächen irgend eine Dicke geben, woher weiß ich

> aber davon und kann ihn ahnden? Aus meinem ideellen Pole, der eben darin begründet ist, der da seine Zeitrevoluzion und seinen Blutumlauf hat, in jenem Raume von vier Dimensionen liegt alles aufgespeichert was wir zu vergessen scheinen, darum scheint es nur daß unsre Gedanken keine Zeit brauchen, freilich keine Zeit wie diese. (Härtl, "Amazonenrepublik" 115–16)

> It is certain that space has to consist of more than three dimensions and time has to have more evolutions than past, present, and future, and thoughts must know a third thing besides subject and object. Do we approach this realm? In the same space which we inhabit now coexists perhaps a different, higher realm for a more elevated perspective of form; the same is true for time. We can not feel this space in the same way as we cannot touch the thickness of one thousand mathematical planes; but how do I know and how do I sense this? Out of my ideal pole that has its origin, its revolution of time and circulation of blood, in a four-dimensional realm in which everything is stored that we seem to have forgotten. That's why it seems, as if our thoughts do not need time; that is, time that is familiar to us.[24]

It is well documented in his earlier notes and Heinz Härtl's recently compiled "Kleine Chroniken" that Arnim experimented with poetry as early as his university years.[25] Although the *Abiturrede* "Das Wandern der Künste und Wissenschaften" ("The migration of arts and sciences") belonged to the rubric of selected topics in the curriculum of the Joachimthalschen *Gymnasium*, the fundamental idea of the connection between art and science is already a central theme.[26] His first novel, *Hollin's Liebeleben*, (*Hollin's Love Life*) was penned when he was writing the three galvanic letters; Raumer's amazement about Arnim as a "horrender Trauerspiel Dichter" (horrendous tragic poet) indicates the friend's knowledge about his literary writings that date back to the beginning of 1798 (WAA 30:69). On December 8, 1801, Arnim mentions his plans for a comedy, *Porcius Procularius Porcellaniunoulus*; on January 26, 1802, he talks about a piece with the title *The Purgatory*; from February until April 1802, preliminary work for *Ariel's Offenbarungen* (*Ariel's Revelations*) is noted. A page with notes about the two-volume travel descriptions of Etienne Marchand's *Die neueste Reise um die Welt in den Jahren 1790, 1791, 1792* (*The Newest Journey around the World in the Years 1790, 1791, 1792*), which was published in 1801–02 in Leipzig, also contains the entry "for the continuation of Ariel." The note is inverted and with similar writing style as the comments on Marchand, which suggests that in 1802 he was already preoccupied with *Ariel's Offenbarungen* that was finally published in 1804. In Paris, he wrote *Erzählungen von Schauspielen* (*Stories of performances*), which was published in Friedrich Schlegel's journal *Europa*. In addition to his longer pieces, he also wrote poetry that he sent to his friends. His plans for a folk song collection, *Des Knaben Wunderhorn* (*The Boy's Magic Horn*) are linked to his "Lebensplan" ("life plan") as a poet, which he outlined in a letter to Brentano. While the earlier works did not receive much recognition, the folk song collection *Des Knaben Wunderhorn* established his literary reputation and situated him with the group of Heidelberg romantics who were no longer interested in the discussion of philosophical themes but actively engaged in the revitalization of German literature.

The model of a complicated interconnected field of tensions that integrates science and art requires the poet as well as the natural scientist to move in "freyer Geistesthätigkeit" ("free mental action") through this force field of knowledge (*Wissen*), science (*Wissenschaft*), and experience (*Erfahrung*). Through his participation the artist can experience firsthand the interaction of the forces in the natural phenomena represented in the conflict as well as the interaction of *natura naturans* and *natura naturata.* Arnim included the "freye Geistesthätigkeit" of man, which he understood as the conflicting relation of reflective and non reflective thought, into the relational structures of nature and expanded the "duplicity" of man and nature into the dynamic triangulation of the "triplicity" of man, nature, and science, or art. In his scientific writings, Arnim does not go beyond the fragmentary and speculative thought experiments that can be reconstructed from the publications and manuscripts. In his art, however, he embraces the creative energies of man, which the artist can represent in the manifold forms as they emerge out of the interrelationship of *natura naturans* and *natura naturata*. In his essay "Von Volksliedern" ("On Folk-Poetry") Arnim states:

> Wenn Genie das Schaffende genannt werden kann, so ist Kunst die Art der Erscheinung dieses Geschaffenen. Genie ohne Kunst wäre Luft ohne Beschränkung, Kunst ohne Genie wäre ein Punkt ohne alle Dimension. (Arnim, *Wunderhorn* 437)
>
> If genius can be called the creating force, then art is the visible form of this creation. Genius without art would be like air without limitations; art without genius would be a point without dimensions.

And he adds:

> Kunst ist Ausdruck des ewigen Daseyns. (Arnim, *Wunderhorn* 453)
>
> Art is the expression of eternal being.

Among the artists, it is especially the poet who becomes the mystic and divines a higher world whose vision he can share with the mundane world through the energy of his imagination. In Arnim's narrative, humans with higher sensory perception play a central role: Raphael in *Raphael und seine Nachbarinnen* (*Raphael and his Neighbors*), Johanna in *Die Päpstin Johanna* (*Pope Johanna*), Isabella in *Isabella von Ägypten* (*Isabella of Egypt*), Melück in *Maria Blainville Melück: Die Hausprophetin von Arabien* (*Maria Blainville Melück: The House Prophet from Arabia*). In the novella *Die Majoratsherren* (*The First Born*), it is the Major who is situated in the liminal space where he perceives the spiritual world in a state between waking and dreaming.

> *. . . und es erschien überall durch den Bau dieser Welt eine höhere, welche den Sinnen nur in der Phantasie erkenntlich wird: in der Phantasie, die zwischen beiden Welten als Vermittlerin steht, und immer neu den toten Stoff der Umhüllung zu lebender Gestaltung vergeistigt, indem sie das Höhere verkörpert.* (Arnim, *Werke* 4:142)
>
> . . . and through the structure of this world a higher world appeared, which could be perceived only through the imagination: through the imagination that mediates between the two worlds and sublimates again and again the dead matter of the shell in living representations by embodying the higher realm.

In this scene, Arnim employs his notion of metamorphosis that creates the link between reality and higher world; through the power of imagination (or spirituality), the "tote Stoff der Umhüllung (ist) zu lebender Gestaltung vergeistigt" ("dead materiality of the shell is spiritualized into a living form"). It is interesting to note that Arnim connects *spiritualized* with *form* and *embodied* with the *spirituality* of the higher world. Spirit and body are no binary oppositions; they create and re-create themselves, just as Arnim conceptualized it in his novella *Raphael and his Neighbors*. It is through the artistic powers of representation that the three-dimensional constellation of author-narrator, text, and reader unfolds. The subject–object relationship as well as the writer–text constellation becomes a dynamic force through the enthusiasm that is passed on to the reader through the medium of the text, and, in turn, inspires her to create and re-create ideas and poetry. Playing with language becomes meaningful: while *spirit*, *spiritual*, and *spiritualization* describe a state, enthusiasm signals the dynamic psychological process that enables the poet to develop the language, which is conceived as fluid, to be molded into form. Arnim says in his essay „Von Volksliedern“ that:

> . . . die Sprache als etwas Bestehendes für sich auszubilden, da sie doch nothwendig ewig flüssig seyn muß, dem Gedanken sich zu fügen, der sich in ihr offenbart und ausgießt, denn so und nur so allein wird ihr täglich angeboren, ganz ohne künstliche Beihülfe. (Arnim, *Werke* 6:174)

> . . . language has to be developed as something that exists as form yet has to remain fluid, so that it can give shape to the idea that is revealed and that emanates from it; only then can it be reborn without any artificial assistance.

The "Anrede an meine Zuhörer" ("Address to my listeners") in the 1812 collection of novellas incorporates the notion of "free movement," which Arnim postulated in his scientific writings as a motion that proceeds "without system through all systems"; furthermore, he transforms that force into a power that energizes the poet's enthusiasm. Because he is situated in this field of tensions, he can link as well as expand the notions of force/spirit and matter/text into a process of "eternal transformation" that takes place in the reception of the reader. Thus Pegasus speaks to the narrator through his own thoughts:

> . . . wisse aber in ewiger Verwandlung und Vergeltung, wird jeder, der den Pegasus zureitet, als Pegasus wieder selbst zugeritten, wer erst Dichter war, wird nachher Begeisterung (denn so heißt das Flügelpferd zu Deutsch) eines dritten, und nur die wenigen, die sich der Begeisterung frei überlassen haben, ohne sie beherrschen zu wollen, die bleiben unverwandelt, und kommen ohne ein solches Leiden zum Urquell des höheren Lichtes, das eben so die Theorie einer andern Welt ist, wie unser Licht, ohne von einer Theorie erfaßt zu werden, die Theorie aller unsrer Naturerscheinungen aufschließt. (Arnim, *Werke* 3:618)

> . . . you have to know that in the eternal change and retribution everyone who breaks in Pegasus will be broken in by Pegasus himself; he who was first poet will become ecstasy (that's the name of the winged horse in German) in a third person, and only the few who have given themselves freely to this ecstasy without the urge to restrain it, remain unchanged and reach the fountain of a higher radiance which is also the theory of the higher world; and similar to our light it will open up the theory of all phenomena of nature without being defined by a theory.

The "Geist" evokes the *Begeisterung* ("enthusiasm") that emanates from the poet into the poetic work, which functions as an intermediary between the artist and reader/listener. Arnim understands the reception of a work of art as a process of "igniting" the "Geist" in the reader who is now shaping and reshaping the old into something new, the past into the present. This *Zeitgeist* lives in ancient artifacts, the fragments of the folk songs, and fairy tales; it will change the collector of the relics of the past into the artist who will transform the "Gewordenes" into a "Werdendes."

Arnim integrates the poetics of the past and the present into the network of forces and bodies; as he argues, only in the continuous system of exchange will the encounter of artist, text, and reader produce endless combinations of art. Arnim connects the notions of work and working, formed and forming again in a complex relationship that he understands as the basis for life and art.[27]

> . . . Mit kleiner Abänderung kann ich sie auf Euch anwenden Ihr Zuhörer (und Leser) der märchenhaften Geschichten, die ich droben im Gebirge einem Zigeuner abhörte, und mit Federn aufschrieb, die einem alten erfrornen Adler ausgerissen, wenn ich annehme, daß ich endlich doch auch meinen Pegasus, statt ihn zu reiten, *zu*reiten wollen, und, darum verwandelt, Euch (wie die Vorzeit) mit meinem *Werke*, nicht als *Dichter* mit meinem gegenwärtigen Wirken [,] in die wunderbaren Klüfte locken möchte, welche eine starke Sehnsucht in jedem zurücklassen, der sie einmal betreten hat, die Seinen erst, und so weiter und die ganze Menschheit dort zu versammeln. (Arnim, *Werke* 3:619)

> . . . With small changes I can apply it to you who listen to (and read) the fairy tales that I heard from a gypsy in the mountains and which I recorded with feathers that I had plucked from an old fro-

> zen eagle. I assume that I finally wanted to break in my Pegasus instead of riding him, and, that I am now changed and can lure you (like in the old times) with my *work*, not as a *poet* with my present labor, into the miraculous cliffs that have left in everyone, who had entered them, a strong longing to assemble here first his friends and then all of humankind.

As he explains in "Dichtung und Geschichte" ("Poetry and History"), the introduction to his historical novel the *Kronenwächter* (*The guards of the crown*), also history and religion are integrated into his system:

> Das Verschwiegene ist darum nicht untergegangen, törigt ist die Sorge um das Unvergängliche. Aber der Geist liebt seine vergänglichen Werke als ein Zeichen der Ewigkeit, nach der wir vergebens in irdischer Tätigkeit, vergebens in Schlüssen des Verstandes trachten, auf die uns der Glaube vergebens eine Anwartschaft gäbe, wenn sie nicht die irdische Tätigkeit lenkte, das Spiel des Verstandes übte, und den Glauben aus der tätigen Erhöhung in Anschauung und Einsicht beglaubigt entgegen träte. Nur das Geistige können wir ganz verstehen und wo es sich verkörpert, da verdunkelt es sich auch. Wäre dem Geist die Schule der Erde überflüssig, warum wäre er ihr verkörpert, wäre aber das Geistige je ganz irdisch geworden, wer könnte ohne Verzweiflung von der Erde scheiden. (Arnim, *Werke* 2:12f)

> The concealed is not perished and the anxiety about the transitory is unfounded. But the spirit loves its fleeting works as a sign of eternity after

> which we strive in vain in our earthly activities, our rational decisions, and which faith would promise as entitlement, if it would not guide our earthly activities, practiced the play of reason and met our faith through the active exaltation in contemplation and insight. We can only understand the spiritual when it is embodied but it is also obscured in that state. If the spirit would not need the education on earth why would it be embodied; but if the spiritual would have become earthly who could depart from the earth without despair?

Arnim's system of the world, as he developed it in his scientific studies, it is not immediately accessible in his published writings. His manuscripts, on the other hand, although fragmentary, reveal a consistent theoretical structure that opens up new venues of understanding his aesthetics. A comparison of his scientific records with his theoretical prefaces, addresses, and correspondence reveals, that Arnim did not perceive the boundaries between the natural sciences and the arts as barriers, but as liminal spaces of intersection that engender endless creative processes.

NOTES

1. Citations of WAA (Weimarer Arnim-Ausgabe) refer to Armin, *Werke und Briefwechsel.* Any numbers that follow designate volumes. Page numbers, if applicable, refer to the commentaries in this edition and appear after a colon.

2. See translation, Harris and Heath, *Ideas for a Philosophy of Nature.*

3. See also Burwick, "Arnims Meteorologie-Projekt" 121–45.

4. For a discussion of Arnim's discourse on speculative philosophy, see Burwick, "'Sein Leben'" 49–89.

5. Although around 1800 "disciplines" in the modern sense had not been established, I am using the term in the essay to characterize the different branches of sciences such as chemistry and physics. I also include in this

term electricity, galvanism, magnetism, meteorology, etc. to explain Arnim's concern about classification and connections.

6. In WAA 4, *Poetisches Frühwerk*, four different texts will be published: *Hollin's Liebeleben, Ariel's Offenbarungen, Aloys und Rose. Französische Miscellen aus Wallis*, and *Erzählungen von Schauspielen*.

7. Härtl, "Kleine Arnim-Chronik" 225–40.

8. The description of the manuscripts and variants and commentaries to individual passages are presented in the edition of the WAA. Page numbers are quoted with superscript r (recto) and v (verso).

9. For Kant's notion of force, see Moiso's essay "Arnims Kraftlehre," in Burwick and Härtl, *Frische Jugend* 85–120. See also Stein's "Naturphilosophie der Frühromantik" 11–16; 39–75.

10. See also Stein, *Naturphilosophie* 39–75. Arnim discusses Schelling's and Steffen's theories again in his 1803 review of Steffen's *Beyträge zur innern Naturgeschichte der Erde* (WAA 2:431–46).

11. See Burwick, "Arnims Meteorologie-Projekt"; Burwick, "Verließ die Physik"; and Burwick, "Ahndung."

12. Arnim is challenging here Franklin's or Gren's theories (WAA 2:14–16).

13. See also the footnote: "Und zwar müssen die beiden gleichen Theile kleiner als der größere seyn, weil sonst unerklärlich bliebe, wie in diesem der neutralisirte Punkt, (Mittelpunkt,) sich habe bilden können." ("And both parts have to be smaller than the bigger one because it would remain unexplained how this neutralized point [the center] had been constructed.")

14. For the controversy with Schelling and Ritter, see also Burwick, "Arnims Meteorologie-Projekt."

15. Armin "Ueber die Wärme"; " Versuche über Verdünstung". Other entries published in Gilbert's *Annalen der Physik* are in Armin, "Gedächtniskrüke." These also include Sign. 03/381, Sign. 03/383, and Sign. 03/387, The recording of barometric readings is excerpted from various journals in Goethe- und Schiller- Archiv Weimar Sign. 03/389. Philosophical and speculative fragments about the topic are in Sign. 03/382 and Sign. 03/384.

16. See Kuhn, *Structure*.

17. See WAA 2:357–61 and 2:193–205.

18. Ibid.

19. See Burwick, "Arnims Meteorologie-Projekt"; and Burwick, "Der Kreis des Wissens."

20. A more precise dating is not yet completed. Part of this convolute is the not yet identified fragment, which Arnim intended to use for his collection of the

history of science (Arnim, "aber ist es nicht aufmunternd").

21. The various fragments and drafts in the folder show numerous emendations that are in most cases immediate corrections. Arnim often preferred to write new drafts instead of editing existing versions.

22. Winkelmann had dedicated his *Einleitung* to his friends Johannes Ritter and Achim von Arnim (81).

23. See my essay on the concept of epigenesis in Burwick, "Verließ die Physik"

24. See Härtl, "Amazonenrepublik," where the entire text is transcribed after the manuscripts in Goethe- und Schiller-Archiv Weimar Sign. 03/254 and 03/258 (Arnim, "Göthe" and "Daß dann auch der Raum"). All quotes are from his text. He dates the text to 1808. See also Andermatt.

25. See Härtl, "Kleine Arnim-Chronik bis zum Ende des Studiums" and "Kleine Arnim-Chronik der Bildungsreise." Härtl has compiled these chronologies from the edition of letters, WAA 30 and 31.

26. WAA 1 contains all the traditional handwritten student publications of Arnim.

27. See Burwick, "Vielschichtigkeit."

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Mathematics around 1800

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Introduction

Why should a book like this have a separate essay on mathematics? After all, the development of mathematics has often been intertwined with the history of the various sciences, especially with physics. Furthermore, in the period we are considering, mathematics and physics were done by many of the same people. From a sociological point of view, too, mathematics has long been one of the sciences. It is organized in similar ways, its practitioners are educated in similar institutions, and it makes similar (if contested) claims to objectivity and to independence from politics and culture. From a philosophical point of view, though, mathematics is different from the natural sciences. Its subject matter is not material, its truths are not falsified by empirical tests, and its results are justified by formal argument alone. This is not to deny the cultural, let alone the scientific, factors that enable the development of mathematics. But more than any other scientific subject, mathematics deals with ideas and procedures that seem to have a life of their own. So the history of mathematics is at once important for science and, in some ways, independent from science.

In what follows, then, we will focus on mathematics in its own right, dividing it up into its conventional subfields: analysis, algebra, number theory, geometry, probability, and statistics. Our primary emphasis will be on the internal development of mathematics. We will of course address institutions, culture, and society when they are relevant. But applications to science will appear only when necessary to tell the story of mathematics itself. To be sure, sometimes mathematics has developed hand in hand with its applications, as we will see in the case of differential equations in the eighteenth century. But often mathematics has developed according to its own internal logic. Mathematicians have pursued questions with no apparent application to the world. Later, though, scientists often discover that these mathematical results constitute exactly what is needed to model and predict the course of nature. A classic example is the way non-Euclidean geometry was used, some eighty years after its invention, in the General Theory of Relativity. The wealth of such examples constitutes another reason for presenting the development of mathematics in a separate exposition.

We shall interpret the phrase *around 1800* broadly, to encompass all of eighteenth-century mathematics. The eighteenth century consolidated and advanced the revolutionary developments of seventeenth-century mathematics: general algebraic symbolism, analytic geometry, calculus, and probability theory. And the nineteenth century—often called the golden age of mathematics—used these developments as the point of departure. The eighteenth century had linked mathematics with the sciences in unprecedented ways. And, both in applied mathematics and in pure mathematics, the eighteenth century found new results and raised new questions. All of this made possible the post-1800 explosion of new abstract concepts, new areas for mathematical research, the founding of mathematical journals and societies, the rise of specialization within mathematics, and the professionalization of mathematics.

The way in which mathematics in the eighteenth century built on the novel ideas of the seventeenth resembles what Thomas Kuhn has called "articulation of the paradigm," the working out of the vast potential of earlier ideas and methods (Kuhn 24). By the 1830s, though, one is tempted to speak of new paradigms, especially in the cases of the rigorization of analysis, the invention of non-Euclidean geometries, and the rise of abstract algebra. But to understand how these dramatic changes could happen, we must first appreciate the sweep of eighteenth-century achievements. To do so, we will first briefly sketch the mathematical inventions of the seventeenth century. Then, in the heart of this essay, we will survey the major areas of eighteenth-century mathematics, often carrying the story forward into the nineteenth century. Some of the discussion will necessarily be technical. But this necessity is part of the historical point being made.

We will also survey the many changes in the institutions of mathematics occurring between the seventeenth and the nineteenth centuries. Many mathematicians in the earlier period were on the payroll of royal courts or of noblemen. The subsequent rise of scientific academies under royal patronage employed mathematicians. These academies brought glory to their patrons, organized research, and, especially through prize competitions, promoted and rewarded work on important problems. Of course, in the eighteenth century, mathematics was taught in schools and universities, but people who learned more advanced mathematics were often self-taught or tutored by practitioners. The eighteenth and early nineteenth centuries also saw modern mathematics' first women contributors, who had to negotiate the institutional barriers of this system of patronage and academies.

We will close our historical survey by addressing the impact of the French Revolution on mathematics and then by describing the beginnings of the nineteenth-century broadening of the center of mathematical action from France into Germany. We will also indicate the way in which many of the revolutionary developments in later nineteenth-century mathematics were already visible in the 1830s.[1] But we will begin by setting the scene for the seventeenth century.

I. The Seventeenth-Century Prelude to Eighteenth-Century Mathematics

Modern mathematics really begins in 1591 with the introduction of general symbolic notation in algebra by François Viète (Franciscus Vieta) in his *In artem analyticem Isagoge* (*Introduction to the Analytic Art*; *Einführung in die Kunst der Analytik*). General symbolic notation means, among other things, that there is only one quadratic equation, not many. Solving the general quadratic equation once by giving the solution in terms of the coefficients effectively solves *every* quadratic equation.[2] General symbolism also reveals the root–coefficient relations for polynomial equations of any degree,[3] and it establishes that an equation of degree n can have no more than n roots. Vieta's innovation pushed the older, more computational algebra toward the study of general structures (Struik, *Source Book* 74–81).[4]

General symbolic algebra quickly bore fruit outside of equation solving. In the 1630s, René Descartes and Pierre de Fermat independently established that every algebraic equation involving two variables corresponded to a curve in the plane, and that plane curves could be described by means of such equations. This fundamental discovery, that there is a one-to-one correspondence between the objects and processes of algebra and of geometry, created a new subject, now known as analytic geometry. The number of possible curves, and therefore the number of possible objects of geometric study, had suddenly become infinite. This was heady stuff.[5]

All geometric problems—such as finding areas, tangents, arc lengths, volumes—could thenceforth be tackled using algebra, and mathematicians of the seventeenth century proceeded to do so. This culminated in the independent invention of a new subject, the calculus, by Isaac Newton and Gottfried Wilhelm Leibniz.[6] The calculus generalized and systematized the methods of solving geometric problems by means of two new concepts, those that we now call the derivative and the integral. The concept of the derivative, whether thought of as a rate of change or as the ratio of infinitesimal differences, and the concept of the integral, whether thought of as the inverse of the derivative or as the adding up of infinitesimal differences, thereafter became objects of investigation in their own right. This meant that, in the eighteenth century, new areas of mathematics—like differential equations, which seek functions that have particular derivatives, and the calculus of variations, which seeks functions that minimize or maximize particular integrals—could arise.

Another extension of the algebraic methods pioneered by Viete, Descartes, and Fermat was their application to infinite processes as well as to finite ones. Instead of being limited to polynomials, algebraists studied and used infinite series, infinite products, and infinite continued fractions. Practitioners of the calculus found derivatives and integrals for functions defined by infinite series, and they used infinite series to solve problems that seemed to have no solution expressible in a finite form. Meanwhile, the physics of Newton's *Principia* provided a fruitful area of application for the calculus and for the subjects that grew out of the calculus.

All these new subjects required means of transmission. The textbooks of the eighteenth century both represented and institutionalized the achievements and methods of the new mathematics. By the middle of the eighteenth century, the materials at hand for mathematical self-education were of a high order. And correspondence between mathematicians provided a virtual community of researchers.

Having completed this brief overview, we are now ready to describe the major areas of eighteenth-century mathematics. We will begin with the most prominent: analysis.

II. Analysis in the Eighteenth Century

1. The interaction between analysis and the physical sciences

The calculus is the mathematics of change. And understanding the physical world means understanding how changes of forces and distances over time are related, as modeled by differential equations. Thus, in the eighteenth century, the engine driving much of the calculus's progress was the need to solve problems in Newtonian physics. Throughout the century—and this is true in many areas of mathematics, not just analysis—the attempt to solve specific problems gave rise to more general methods. In analysis, mathematicians began to raise concerns by the end of the eighteenth century about the logical foundations of the subject that had been so successful in solving problems, concerns that were not fully alleviated until the 1860s.

First, then, to the progress of analysis as linked to physics: Beginning in the 1690s, Leibniz's disciples were beginning to apply differential equations to physical problems. For instance, in 1696, taking advantage of one of the new scientific journals, Johann Bernoulli posed in the *Acta eruditorum* the problem of identifying the "curve of quickest descent"—that is, the path along which a falling body moving without friction would descend fastest (Struik, *Source Book* 391–99). The problem was solved by Newton, by Leibniz, and by Jakob Bernoulli, as well as by Johann himself: the curve is a cycloid. Johann's was the most important solution because it involved finding the function that produced the minimal value of an integral and thus pointed to a general question about maximizing or minimizing integrals. The first general theory to address this question was developed in 1744 by Leonhard Euler, who used a polygonal approximation to the integral in order to find a necessary condition that the integral be a maximum or a minimum (Struik, *Source Book* 399–406). In 1755, the young Joseph-Louis Lagrange devised an analytic method (Struik, *Source Book* 406–13) that he explained to Euler in a letter. Euler presented Lagrange's method to the *Académie des Sciences* of Berlin and, in 1762, encouraged Lagrange to publish his new method in the *Miscellanea Taurinensia*. This episode not only marks the origin of a new subject, what is now called the calculus of variations, but also provides an instructive example of the nature of scientific organization and communication in the eighteenth century.

Meanwhile, in 1716, Jacob Hermann, originally a theology student in Basel who was encouraged to enter mathematics by Jakob Bernoulli and then patronized by Leibniz, began the process of translating Newton's physics from the geometric style of the *Principia* into the language of Leibniz's differential calculus. Hermann's work included such Newtonian results as proving that a central force implies Kepler's equal-areas law and that an inverse-square force law means that the orbit of a planet is a conic section (Katz 589–92). Inspired by such uses of the calculus to express and derive physical results, Euler showed that the differential equations governing vibrations could be solved in closed form by using the trigonometric and inverse trigonometric functions. The mathematical solutions gave new physical results, including predictions of the periods of vibration. And, going beyond the physics, Euler developed all the basic calculus of the trigonometric functions, treating them for the first time as general mathematical functions rather than mere geometric objects in triangles. This new conception of the trigonometric functions, in turn, led Euler to his classic method of solving linear differential equations with constant coefficients by using characteristic polynomials. Johann Bernoulli criticized some of Euler's methods because they implied that the complex roots of the characteristic polynomial were related to real, not imaginary, values of sines and cosines. Euler responded by showing the equivalence of these different forms, thereby both relating complex variables to real physical problems and highlighting the importance of complex variables in analysis. Euler also defined the logarithms of negative and complex numbers and related them to the trigonometric and exponential functions. As all this illustrates, Euler was motivated by physical problems but also fascinated by—and deeply engaged in finding—their analytical representation.

Meanwhile, since the curve of quickest descent had turned out to be the cycloid, Johann Bernoulli decided to study families of cycloids and curves orthogonal to them. These considerations led to the calculus of several variables and therefore to the study of rates of change of functions of several variables, producing what are now called partial differential equations. Solving problems about families of curves yields to relatively simple Leibnizian methods if algebraic equations for the curves are known, but it is harder when the curves are given as integrals. Leibniz made some progress on such problems by formulating a general result about the interchangeability of the operations of differentiation and integration. Nicolaus Bernoulli, a nephew of Johann and Jakob, added the ideas of a total differential, and the equality of the mixed-order second differentials, to the study of the calculus of functions of two variables. Meanwhile, first the Bernoullis and then Alexis-Claude Clairaut in 1731 started working with what are now called double integrals. In 1769, Euler gave the first systematic explanation of double integrals, interpreted such integrals as volumes, and transformed such integrals by changes of variables (Katz 593–96, 601–08). All these powerful and general arguments were formal; Euler assumed that the relevant integrals and derivatives always existed, a type of assumption common in eighteenth-century analysis. For Euler and his contemporaries, the power of the methods far outweighed worries about possible limitations.

Another important example of a physical question that produced mathematical advances was the problem of the vibrating string (Struick, *Source Book* 351–68).[7] If we pluck a guitar string, the position of a point on the string depends both on the distance of that point from the end of the string and on the time of vibration. Thus, the problem requires the solution of a differential equation involving two distinct variables. Jean le Rond D'Alembert in 1747 addressed the vibrating-string problem by proposing the partial differential equation now called the wave equation. He said that the physics of the situation required the function that solved the equation to have some specific properties, such as being periodic. But beyond this, d'Alembert asked, what other properties did the function solving the equation need to have? And what were its solutions?

D'Alembert thought that the function had to have an explicit formula and to be differentiable at every point. But Euler was willing to relax these requirements, allowing a function to be representable as a curve drawn freely by hand, allowing the function to be discontinuous at individual points, and even proposing that a function could have different formulas over different intervals. Then, in 1753, Johann Bernoulli's son Daniel, motivated by the physical idea that a vibrating string potentially represents infinitely many tones, suggested that the solution ought to be representable by an infinite series of trigonometric functions. Thus the problem of the vibrating string provoked a debate over the notion of function, helped propel the function concept into the list of fundamental ideas in analysis, and, not so incidentally, got mathematicians interested in trigonometric series. The detailed study of trigonometric series by Joseph Fourier in the early nineteenth century in the context of a different physical problem—the flow of heat—by means of partial differential equations became an important part of nineteenth-century analysis (Birkhoff 130–56). Fourier's treatment of trigonometric series as functions even entered the study of the logical foundations of analysis when Niels Henrik Abel gave a trigonometric series to show that, contrary to a supposed theorem given by Augustin-Louis Cauchy, an infinite series of continuous functions need not itself be continuous. Even later, trigonometric series developed in order to solve particular physical problems were crucial in the development of the abstract function concept by Peter Gustav Lejeune-Dirichlet, Eduard Heine, and Richard Dedekind in the later nineteenth century.

2. Communicating results in analysis to the scientific community

All of this progress in calculus meant that there was an increasing demand for textbooks. The first actual textbooks were far from elementary: Guillaume François l'Hospital's *Analyse des infiniment petits*, based on Johann Bernoulli's lectures and released in 1696, was truly state of the art (Struik, "Origin"; *Source Book* 312–15), and the same is true of Newton's *Method of Fluxions*. By the middle of the eighteenth century, texts by Maria Gaetana Agnesi, Colin MacLaurin, and Leonhard Euler provided mathematically sophisticated and systematic introductions to the calculus.

Agnesi's *Instituzioni analitiche ad uso della gioventù italiana* (*Analytical Institutions, Grundlagen der Analysis*, 1748) was the first major mathematical work in history to be authored by a woman. Her goal was to provide complete explanations for all of analysis. Beginning with algebraic equations and analytic geometry, her book explained differential calculus, integral calculus, and the solving of differential equations. She drew on contemporary research by men like Jacobo Riccati, the Bernoullis, and Euler, as well as on earlier textbooks like that of l'Hospital. For theological reasons, Agnesi held that the perfect truths of reason need to be protected from the material contamination of the senses, so her book did not address mechanical and empirical considerations. Nor did she follow the purely analytic style of Euler; instead, she preferred a more geometric approach. Still, this was an up-to-date textbook notable for its clarity. Her book gave the first systematic presentation of Italian terminology for the concepts of the calculus, and it was influential far beyond its Italian setting. Sections of it were published in a French translation in 1775, and the whole book was translated into English by John Colson, who had been a translator of Newton.[8]

MacLaurin's *Treatise of Fluxions* (1742) was begun as a response to criticisms of the rigor of the calculus leveled by George Berkeley in the *Analyst* of 1734. But the *Treatise* as published was much more than a reply to Berkeley; it grew into a major expository work. The book included the first explicit definition of the sum of an infinite series as the limit of what we now call the partial sums, the definition of the slope of the tangent to a curve as the limit of the slope of the secant lines, influential material on the theory of extrema, studying functions by infinite series, and the mathematical theory of the shape of the earth. MacLaurin's *Treatise* served to transmit Newtonian ideas in calculus, improved and expanded, to the Continent.[9] The French translation in 1749 by the Jesuit R. P. Pézénas was used by Lagrange, who praised the way MacLaurin had translated Newton's physics into analytical language. MacLaurin's analytic treatment of infinite series was singled out for special praise by Silvestre-François Lacroix in the historical introduction to the second edition of his monumental and highly influential end-of-century calculus textbook.

And Leonhard Euler produced three great textbooks, all published in Latin. The first volume of his *Introductio in analysin infinitorum* of 1748 (*Introduction to the Analysis of the Infinite*) dealt with infinite series, infinite products, and infinite continued fractions. For the first time in analysis, functions, not curves, were the major object of study. Euler distinguished between algebraic and transcendental (that is, trigonometric, exponential, and logarithmic) functions and gave the first recognizably modern theory of the transcendental functions and their power series expansions. The trigonometric functions are described in terms of arcs in a unit circle, and Euler derived their power series in a *tour de force* involving the binomial theorem, complex numbers, and a cavalier treatment of infinites and infinitesimal.[10] The second volume of the *Introductio* skillfully deals with the applications of the analytic results to geometry, all done without making any explicit appeals to the concepts of the calculus.

The formal treatment of algebraic objects in Euler's *Introductio* exemplifies the widespread eighteenth-century belief in the universal power of symbolic reasoning, a belief that had implications for philosophy. Leibniz had sought a "universal characteristic" that would translate all reasoning into a symbolic and therefore decidable form. This view is consistent with Leibniz's notation for the concepts of the calculus, *dy/dx* and $\int f\,dx$, notations whose heuristic power makes them still popular today. The same idea underlies the formalistic approach to mathematics characteristic of some late eighteenth-century mathematicians, like the French François-Joseph Servois and the German Carl Friedrich Hindenburg, and nineteenth-century Britons, including George Peacock and Augustus De Morgan.[11] This idea, that mathematics is an almost mechanical process of manipulating formal symbols, was adopted by Charles Babbage in his quest to make all of calculation literally mechanical as he conceived of an "analytical engine," or digital computer. In the same tradition, the Marquis de Condorcet wrote that the success of algebra came because "it contains within it the principles of a universal instrument, applicable to all combinations of ideas." Condorcet added that such an instrument "could make the progress of every subject embraced by human intelligence . . . as sure as that of mathematics" (Condorcet 278–79).

In 1755, Euler produced another great text, the *Institutiones calculi differentialis* (*Institutions of the Differential Calculus)*. In one respect it is like Agnesi's book in eschewing physics. But Euler, unlike Agnesi, treated the calculus as pure analysis, which had no need of geometric diagrams. In this 1755 text, Euler presented the standard differential calculus for all the functions treated in his *Introductio* of 1748. He treated extrema in the same way that MacLaurin had, although with more examples and without the geometric motivation. And Euler gave a full exposition of partial derivatives, including an argument that the mixed partial derivatives of a function of two variables are equal.

Finally, Euler's *Institutiones calculi integralis 1768–1770* (*Institutions of Integral Calculus*) gave a thorough account of integration based on many new results of his own. Instead of defining the integral as a sum or an area, as Leibniz and the Bernoullis had, Euler, in what became the typical eighteenth-century fashion, treated integration as the inverse of differentiation. He systematically showed how to integrate functions by means of substitution, by infinite series, and by integration by parts. He solved differential equations by a range of methods, including separation of variables, and addressed partial differential equations as well as ordinary ones. Again, there was no geometry or physics in this book. Nonetheless, the techniques in Euler's textbooks were and still are essential to the analysis of physical problems, as the nineteenth-century history of topics ranging from heat flow to electromagnetism makes clear.

Readers who look at Euler's texts instead of his published articles and the articles of men like the Bernoullis and d'Alembert will see the major techniques and concepts underlying eighteenth-century analysis but will miss the range of applications to areas, volumes, tangents, and curvatures, and may remain unaware of the physical problems that motivated and accompanied much of the original reasoning. Still, Euler's books display the heart of eighteenth-century analysis and had wide influence. The *Introductio* in particular was reprinted repeatedly and translated into French and German, and the *Differential Calculus* soon translated into German, although the *Integral Calculus* remained just in Latin until 1828. There were various other works on the calculus, of course, including relatively elementary ones. As we will see later on, the entire textbook picture was transformed with the French Revolution, together with changes in the social role of mathematicians, and with changes in mathematics education in general.

Our earlier emphasis on the advances in analysis, and even our description of these textbooks, has largely neglected the question, what is the true nature of the concepts of the calculus? In the eighteenth century, this was often treated as a philosophical rather than a mathematical question: What is the true metaphysics of the calculus? But it was a mathematical problem as well. Ideas like *infinitesimal* or *infinite* contradicted the Euclidean theory of magnitudes; ideas of velocity and rate of change appeared to bring physical ideas into pure mathematics; and the idea of limit, which to modern mathematicians is unproblematic because of its current rigorous definition, was then an intuitive idea of insufficient generality. And don't think these difficulties went unnoticed.

The most intellectually powerful critic of the foundations of eighteenth-century calculus was George Berkeley. In 1734, Berkeley attacked the logical rigor of all of eighteenth-century calculus. Berkeley was a philosopher and theologian, and he had profound reasons to attack much of eighteenth-century science. But that fact doesn't make his arguments wrong. Berkeley said that nobody had, or could have, a clear idea of infinitesimals. He argued convincingly that all the existing arguments about limits began by treating the increments in variables as finite, and then at the end of the calculation discarded the increments as though they were zero; that, he said, is a contradiction. He added that mathematicians preferred "to compute rather than to think" and that their algorithms nevertheless worked only because the errors they made cancelled each other out—"a compensation of errors" (Berkeley).[12]

Several of Berkeley's mathematical contemporaries tried to address these criticisms. For instance, Colin MacLaurin showed that one could get the major results of the calculus by using indirect proofs and basing these proofs on inequalities between constant and varying velocities. D'Alembert gave explicit algebraic limit computations, at least in a few special cases, although he did not provide a general foundation. Lazare Carnot had the clever idea of proving Berkeley's contention that the truth of the calculus rested on the compensation of errors by showing that the errors always cancel each other out, but, although his work attracted attention, Carnot did not succeed in this goal.[13] Lagrange, granting Berkeley's criticisms, tried to get rid of all the old justifications of the calculus—infinitesimals, infinitely small differentials, limits, and rates of change—seeking to base the calculus entirely on algebra, thus reducing the calculus to what he called algebraic analysis. Lagrange, however, followed Euler in believing that there was an unproblematic algebra of infinite series. So, although Lagrange pioneered algebraic delta-epsilon-style proofs that he based on his infinite-series foundation for the calculus, he did not rigorize the calculus successfully.[14] Furthermore, none of these attempts to answer Berkeley's criticisms adequately linked their supposed rigorous foundations to the intuitions behind the calculus. It was left to Augustin-Louis Cauchy and Bernhard Bolzano in the early nineteenth century to successfully (or almost successfully) reduce the calculus to algebraic analysis, and to Karl Weierstrass and his school in the 1860s to complete the job.

Cauchy and Bolzano both were inspired by Lagrange's idea that the calculus should be reduced to the algebraic analysis of finite quantities. Cauchy, in his magisterial lectures at the Ecole Polytechnique in the 1820s, consistently and precisely reinterpreted the earlier verbal statements about limits of variables into the language of the algebra of inequalities.[15] Thus, for instance, "the derivative of a function is the limit of the quotient of the increment in the function and the increment of the independent variable" became instead something like this: "if epsilon is a small number, the absolute value of the increment in the independent variable can be chosen sufficiently small so that the absolute value of the difference between the derivative of the function and the ratio of the increments of the function and the independent variable can be made smaller than epsilon" (Cauchy, *Leçons* 22–23, 44–45). Cauchy proved many theorems, including the mean-value theorem for derivatives and convergence tests for infinite series, using the algebra of inequalities. Realizing, too, that defining the integral as the inverse of the derivative assumed both the existence of the integral and its ability to be approximated as a sum, Cauchy redefined the integral as the limit of sums and gave the first reasonably rigorous proof for the existence of the definite integral of a continuous function.[16]

Cauchy also proved the intermediate-value theorem for continuous functions, combining algebraic techniques used by Lagrange and his own insights about real numbers. Independently, Bolzano, in 1817, had already applauded Lagrange's call for a proof of that theorem, devastatingly critiqued Lagrange's own attempted proof, and gave what he called, in a Lagrangian-style phrase, a "purely analytic proof" of the theorem.[17] In the 1830s, Bolzano provided a series-based treatment of the calculus whose title, *Functionenlehre*, reveals the initial impetus of Lagrange's *Théorie des fonctions analytiques*, but Bolzano's book had much greater rigor. Although Bolzano's work became known only in the second half of the nineteenth century—his lack of a major teaching position, his reputation as a philosopher and theologian, and his relative isolation in Bohemia being partly responsible—his simultaneous discovery of some of Cauchy's results testifies to the *Zeitgeist*: individual results in calculus were now perceived to require justification, and the algebraic techniques of the eighteenth century were at hand to provide the methods of proof for that justification. Some questions unanswered by the work of Cauchy and Bolzano were cleared up as the century proceeded, as we shall indicate a bit later on.

It may seem surprising that one hundred fifty years elapsed between the invention of the calculus by Newton and Leibniz and the first successful work to establish Euclidean-style rigor for the subject. However, there have been times in the history of mathematics when demanding proof, rather than plausibility arguments, was premature, and the eighteenth century was such a time. The great progress of the calculus in that century did not require the full delta-epsilon theory that justifies the true results and infallibly rules out the false ones. Waiting for that theory, a theory that was conceptually difficult, would have substantially impeded progress. Things other than rigorous proof kept analysis honest: intuition, numerical checking, and successful applications to the natural world. In the eighteenth century, these largely sufficed.

In fact, a major incentive for the new rigor was neither the criticisms of Berkeley nor the perception that there were errors that needed correction. Instead, it was the need to teach. For instance, Lagrange's foundations of calculus were delivered in 1797 as a series of lectures at the Ecole Polytechnique in Paris, and Lagrange said that he had first thought about the foundations of the calculus when lecturing at the military school in Turin in 1754. Cauchy's "foundations" were part of his great *Cours d'analyse* at the Ecole Polytechnique. Weierstrass's work on foundations of analysis came from his lectures at Berlin. Dedekind, who in his *Was sind und was sollen die Zahlen* of 1872 gave a classic treatment of the nature of real numbers, said that he began thinking about the nature of numbers as a result of his earlier lecturing in Zurich. Recall that, in the seventeenth and eighteenth centuries, mathematicians often had been supported by patrons. But starting with the Ecole Polytechnique, professional mathematicians by and large became teachers in institutions of higher education. And the need to teach classes—to systematically present a complicated subject to people not already working with the concepts—focused mathematicians' attention on the nature of the basic concepts and their most essential properties.[18]

But that's not the whole story either. Although delta-epsilon proofs were not needed for the eighteenth-century progress of the calculus, eventually they became absolutely crucial to the development of analysis. There comes a point, even in the applications of the calculus, where failure to make key distinctions, to have unexceptionable definitions, produces mistakes. So, for instance, in a discovery that invalidated Lagrange's infinite-series foundations for the calculus, Cauchy found distinct functions that had the same Taylor-series expansions. Later on in the nineteenth century, Bernhard Riemann showed that a function didn't need to be continuous in order to have a definite integral. He gave conditions on integrability, and he both broadened and made more precise the concept of the definite integral.[19] Bolzano, Riemann, and Weierstrass, among others, found functions that are everywhere continuous and nowhere differentiable—something not only unanticipated but counterintuitive.

The distinctions that were made as a result of these new discoveries—for example, the distinction between pointwise and uniform convergence—gave rise to a whole new set of mathematical objects, objects which lie even farther beyond intuition than do the concepts of the calculus. One example is the way in which Georg Cantor's theory of the infinite arose out of asking about the structure of the sets of real numbers on which Fourier series converge. Cantor's question could not even have been formulated in eighteenth-century mathematical language, but in the 1870s it produced the whole theory of infinite sets and transfinite numbers. The highly imaginative theories that have arisen since, including infinite-dimensional spaces, turned out to have applications to quantum mechanics—another illustration of the unpredictable way mathematics and its applications can interact.

III. Algebra in the Eighteenth Century

Eighteenth-century algebra was largely about solving equations: exactly if possible, approximately if necessary. Algebraists had inherited from antiquity the solutions of quadratic equations, knew the sixteenth-century solutions of the general cubic and fourth-degree equations, and had internalized the techniques based on the symbolic notation of Vieta. They also were armed with Newton's general binomial theorem and with various methods of solving algebraic equations approximately by means of infinite series and infinite continued fractions. Eighteenth-century algebraists extended the older theory of equations and also used techniques from analysis to help find solutions.

In the seventeenth century, Albert Girard had conjectured that a polynomial equation had exactly as many real and complex roots as its degree,[20] a result now known as the fundamental theorem of algebra. Leibniz found this idea especially interesting because it was closely related to a problem in analysis: can every rational function be integrated by being broken up into partial fractions? D'Alembert tried to prove a form of Girard's result in the 1740s, and his argument gave mathematicians another reason to be interested in complex numbers. Euler also tried to prove the fundamental theorem of algebra by using the intermediate-value property for continuous functions and studying the *n*th roots of unity. The general theory of equations remained relatively elementary, however, until Lagrange took up the subject in the

1770s. A complete proof of the fundamental theorem of algebra had to wait both for Johann Carl Friederich Gauss's theory of complex numbers and the nineteenth-century proofs of the intermediate-value theorem for continuous functions.

By the middle of the eighteenth century, several textbooks had presented the algebra of the time systematically. Newton's lectures on algebra at the University of Cambridge were put together in 1707 under the title *Arithmetica Universalis* (*Universal Arithmetic*).[21] The concept expressed by the title of Newton's book justifies the manipulation of algebraic symbols, since algebra was seen as nothing more than a generalized abstraction from the laws of arithmetic. This same conception appeared in the *Treatise of Algebra* by Colin MacLaurin, who included negative numbers in his subject matter; MacLaurin's work is perhaps best known for its treatment of simultaneous linear equations by what later became called Cramer's rule. Euler's *Vollständige Anleitung zur Algebra* treated imaginary quantities as well as real ones and included infinite series and logarithms. It was Euler who introduced or popularized many of the now conventional algebraic notations, most notably e for the base of natural logarithms. In his *Algebra*, Euler also treated Diophantine equations, that is, indeterminate equations that have more than one rational solution.

All these algebra books reflect the standard eighteenth-century views of their subject. It was Lagrange, though, who went the farthest beyond solving particular types of equations. Algebra, for him, was more than just a "universal arithmetic"; it was the study of general systems of operations. In a seminal paper of 1770[22] on what he called "the algebraic theory of equations," Lagrange studied the relationship between the roots of a polynomial equation and what he called the "reduced equation"—a type of auxiliary equation whose solution, in the case of the cubic and fourth-degree equations, enabled the original equation to be solved. He showed how the reduced equation depended on the permutations of the roots of the original equation. By focusing on the structure of the set of such permutations of the roots, Lagrange was able to determine conditions on the possible reduced equation that would render the original equation solvable. More precisely, if there are *n* roots to an *n*th degree equation, the reduced equation should have a degree smaller than *n* under all of the *n*! possible permutations of the roots. Lagrange showed, among other things, that the degree of the reduced equation had to divide *n*!, a result which, when redefined in terms of the nineteenth-century concepts of group and subgroup, is now called Lagrange's theorem.

Lagrange was unable, since it can't be done in general, to find the function of the roots that would take on the right number of values while the roots were permuted, but the concepts he introduced were later built on by Paolo Ruffini in his attempted proof—and by Niels Henrik Abel in 1829 in his successful proof—of the unsolvability, by algebraic means, of general polynomial equations of degree higher than four. Meanwhile, in 1815 the theory of permutations and the structure of sets of permutations were developed further by Cauchy, who defined what are now called cyclic permutations, inverses, and subgroups. Slightly later, Evariste Galois identified what he called the permutation group of an equation, invented the concept that we now call a normal subgroup, and gave conditions for the solvability of algebraic equations based on these ideas. These nineteenth-century results about solvability in general exemplify the way nineteenth-century mathematics, in its pursuit of generality and in its standards of proof, went beyond eighteenth-century concerns with specific types of problems and processes of solution.[23] We will see some more algebraic examples when we come to discuss the work of Gauss.

In the nineteenth century, the laws of the formal manipulation of symbols became codified. In 1814, François Joseph Servois coined the terms *commutative* and *distributive* for operations, and he even imagined that there could be examples where these laws might not apply. George Peacock, sometimes called the Euclid of algebra because of his clear presentation of algebra's basic principles, wrote a *Treatise on Algebra* in 1830 which distinguished universal arithmetic, which he called arithmetical algebra, from symbolic algebra, where the symbols and their rules of combination did not need to be applied to anything.[24] Peacock spoke of symbolic algebra quite abstractly, as "combinations of arbitrary signs and symbols by means of defined though arbitrary laws" (71). Peacock gave no examples of this theoretical possibility, but it became real when William Rowan Hamilton created a new consistent algebraic system—the quaternions—that had a noncommutative multiplication.[25] Hamilton's "violation" of the commutative law still seemed to be about something, since he saw algebra in a Kantian way as the science of "pure time."[26] And quaternions, much like vectors, are applicable to the physics of rotations. Nevertheless, Hamilton had taken a key step in the direction of later views like that of the American Benjamin Peirce, who in his 1870 *Linear Associative Algebras* (note the plural!) characterized mathematics as independent of any external criterion for its axioms or its applicability, saying, "Mathematics is the science that draws necessary conclusions."

IV. Number Theory in the Eighteenth Century

The theory of numbers goes back to the Greeks, and Pythagorean number theory focused on properties of the natural numbers. Eighteenth-century number theory addressed these questions too, but also owed a great deal to the seventeenth-century publication of Diophantus's *Arithmetica* and the application of symbolic algebra to its problems. Perhaps the most famous example of Diophantus's influence is what is now called Fermat's Last Theorem. Fermat made a marginal note to a result of Diophantus about sums of squares, saying that although Pythagorean triples—numbers a, b, and c such that $a^2 + b^2 = c^2$—are abundant, there are no numbers a, b, and c such that $a^n + b^n = c^n$, if n is a whole number greater than 2. Fermat wrote that he had discovered a remarkable proof of this result that the margin was too narrow to contain (Fermat's conjecture was finally proved in the late twentieth century, by methods far more sophisticated than anything available in 1800, let alone in Fermat's time). Euler proved Fermat's conjecture for $n = 3$ and 4. Later, Sophie Germain, a woman who adopted a male pseudonym in order to be able to have a mathematical career, found conditions that a prime value of n needed to satisfy for Fermat's theorem to hold for it; this enabled her to show that any solutions for degree 5 would need to be very large (on the order of 10^{39}).[27] Further attempts to prove the theorem by focusing on prime values of n at first seemed promising, but in 1844 Ernst Kummer became aware that the factorization of what are now called cyclotomic integers, a class of complex numbers, is not unique, and so some of the methods proposed for Fermat's theorem would not work. Results like Kummer's led to a great deal of interesting abstract algebra, including the algebraic number theory and ideal theory of Richard Dedekind in the 1870s. Again, a particular problem led to a set of fruitful generalizations, but this time the more powerful nineteenth-century methods were not able to solve the problem.

Other important ideas in number theory were prominent in the work of Euler: his theory of divisibility of the whole numbers, of congruence with respect to particular numbers, and of residue classes.[28] Euler applied this idea to numbers in arithmetic or geometric progression, and then to quadratic residues as well. Following up on Euler's work, Adrien-Marie Legendre also attacked the problem of quadratic residues, focusing on numbers that are quadratic residues of one another, thus making progress on proving what is now called the law of quadratic reciprocity.[29]

Number theory provided a fertile field for the power of symbolic algebra. Euler in particular made many contributions to number theory and its relationship with other branches of mathematics. He extended Fermat's work on relatively prime numbers, ultimately leading Lagrange and Gauss to a more general theory of binary quadratic forms. Euler studied the patterns formed by prime numbers and by the divisors of composite numbers. He also studied how many ways a positive number can be obtained as the sum of positive integers—the so-called partition problem. These questions led him to study infinite products involving the positive integers, including what is now called (when applied to functions of a complex variable) the Riemann zeta function.[30] Thus Euler's work began the nineteenth-century process of bringing results from analysis into number theory.

Number theory has long attracted the best efforts of prominent mathematicians, but it had virtually no applications (except to other areas of mathematics) until the late twentieth century. In the computer age, though, number theory has become the heart of modern cryptography, and some recent work on prime numbers has been classified as secret by government agencies—again illustrating the way in which mathematics devised for one purpose, given changes in society and technology, can be used for something quite different.

Much of eighteenth-century geometry was closely related to algebra and analysis as a result of the discovery of analytic geometry. The calculus greatly advanced geometrical knowledge because of its applications to tangents, areas, volumes, and curvature. But synthetic geometry continued to have an independent existence. In particular, eighteenth-century geometers, in part because of the prestige of the Euclidean model of reasoning (exemplified both by Newton's *Principia* and works like Baruch Spinoza's *Ethics Demonstrated in Geometrical Order*) and in part because of the Newtonian emphasis on the infinity and symmetry of space, became especially interested in the ancient problem of trying to prove Euclid's parallel postulate from his other postulates.

First, though, let us look at analytic geometry. Euler, in the second volume of his *Introductio*, described curves given by functions, including the properties of all curves of degrees 2, 3, and 4; looked at exponential, logarithmic, and trigonometric curves; and used polar coordinates to describe spirals. He also dealt with three-dimensional surfaces as described by three variables. He, and also Alexis Clairaut, began the investigation of space curves—that is, nonplanar curves in three-dimensional space.

All this work meant that a systematic textbook in analytic geometry was possible, and a highly influential one was written in 1807 by Gaspard Monge. Not only did Monge work out the elementary analytic geometry of two- and three-dimensional space using coordinate systems: he showed how to apply the calculus to find tangent planes, normal lines, and the partial differential equations that represent particular surfaces. Also, Monge was the founder of descriptive geometry, the method of representing three-dimensional objects on two mutually perpendicular plane surfaces, familiar to modern readers from architectural plans. Thus Monge helped revive interest in synthetic geometry even in the analytical stronghold of France. As we shall see, his teaching about geometry, both at the Royal Engineering School at Mézières and later at the Ecole Polytechnique, had a major impact on the next generation of engineers, mathematicians, and scientists in France.[31]

Now that we have returned to synthetic geometry, let us look at Euclid's fifth postulate, the so-called parallel postulate.[32] Because Euclid's postulate five did not seem self-evident like his other postulates, mathematicians had long thought that assuming it rather than proving it was a flaw in his geometry. In the eighteenth century, this attitude was exemplified by the title of a book by Gerolamo Saccheri (1667–1733), *Euclid Freed from All Imperfections* (1733), in which, Saccheri thought, he had proved the fifth postulate by assuming that it was false and finding that a large number of apparently absurd things follow. What Saccheri had done, though—and what later mathematicians like Johann Heinrich Lambert, Legendre, and Lagrange, who tried the same thing did—was to work out a set of consequences of the denial of postulate five, such as the nonuniqueness of parallels, or that a quadrilateral with three right angles need not have a fourth right angle. These conclusions seemed contrary to eighteenth-century intuitions of space, contrary even to the idea of straight lines. However, as it turned out, they were not therefore logically contradictory.

Still, even Lambert, the most radical of the eighteenth-century geometers who worked on postulate five, never completely got past the Euclidean mind-set. Lambert worried that the logical necessity of Euclidean geometry could not be proved, and he had spent a lot of time trying. He even briefly suggested that a sphere with imaginary radius, whatever that might be, could have a geometry where the parallel postulate was false. But Lambert did not conceive of a full-blown non-Euclidean geometry, and neither did anybody else in the eighteenth century.

In the early nineteenth century, though, three people, more or less independently, were struck by the same realization: these conclusions are not contradictory, or illogical, or absurd at all. They are perfectly valid theorems, but in a different geometry, a geometry that is not Euclidean.[33]

The first inventor was Carl Friedrich Gauss. Gauss's work on the curvature of surfaces, in part motivated by geodesy, got him interested in the basic assumptions of geometry, and in his manuscripts he developed the basic ideas of a two-dimensional non-Euclidean geometry as early as 1816. This new geometry challenged the prevailing Kantian view that space was a unique a priori intuition of the intellect; Gauss thought instead that the nature of space was a question for physics. But Gauss did not develop the new geometry fully, and he chose not to publish on the subject. It was left to Janos Bolyai and Nikolai Ivanovich Lobachevsky to publish the first accounts of non-Euclidean geometry. Though in a relatively obscure place, Bolyai published in 1831; when Gauss, though praising Bolyai, claimed priority over him, Bolyai left off doing mathematics altogether. Meanwhile, Lobachevsky had published his independent discovery of non-Euclidean geometry in Russian in 1829 and then, more influentially, in German in 1840. Lobachevsky, too, wondered whether physical space was Euclidean or not, and he even tried to use star positions to check whether there was a lower bound to observed stellar parallaxes, as would occur in a highly curved Lobachevskian space but not in a Euclidean one. But, within the limits of measurement, he could not tell.[34]

Non-Euclidean geometries were potentially revolutionary for mathematics but became part of the mathematical mainstream only with the work of Riemann, who generalized the idea of space and distance to multiply-extended manifolds, for which three-dimensional Euclidean space with the Pythagorean sum-of-squares distance was only one of an infinite number of possibilities (Gray, *Ideas* 140–46). Later in the nineteenth century, mathematicians like Eugenio Beltrami, Felix Klein, and Henri Poincaré constructed models of non-Euclidean geometries in Euclidean space, making clear that Euclid's fifth postulate is in fact independent of the others, and that non-Euclidean geometries are independent mathematical structures. The philosophical impact of the view that real space might not be Euclidean and that we may not know the nature of space at all was eventually enormous but was delayed until later in the nineteenth century, when Hermann von Helmholtz and W. K. Clifford addressed the question of the nature of space and the empirical, if limited, knowledge we can bring to bear on the question. Since the twentieth century, non-Euclidean spatial ideas have had an impact on art and architecture, as well as in physics through Einstein's general theory of relativity.[35]

The other novel geometrical creation of the eighteenth and early nineteenth century was projective geometry. This subject owes its origin to the study of the projections of three-dimensional objects onto the plane, as developed by Renaissance artists. Piero della Francesca, in the fifteenth century, wrote a seminal treatise on the geometry of perspective as applied to painting. The use of perspective in painting provides a remarkable example of applied mathematics, although for most painters—Piero della Francesca, Leonardo da Vinci, and Albrecht Dürer are exceptions—it was a learned practice rather than a mathematically understood theory. The first sophisticated theoretical mathematical work on what we now call projective geometry is due to Descartes's contemporary Girard Desargues in 1639.[36]

Monge's work, already discussed, was also important. And it was a student of Monge, Jean-Victor Poncelet, who in 1822 wrote the first definitive work on projective geometry. Monge had projected geometrical figures onto two mutually perpendicular planes. Poncelet asked which properties of geometrical figures were invariant under all projections. Size and shape clearly are not, but intersections between lines are, provided that one allows parallel lines to "intersect" at a point at infinity, and if one defines all the points at infinity as making up a line at infinity. Among many other pleasing results, projective geometry unifies the theory of all the conic sections in an elegant and fruitful way.[37] Felix Klein later showed that distances (or, as they are now called, metrics) in the projective plane can be used to characterize different types of geometries, whether Euclidean or non-Euclidean. Klein also used the algebra of group theory to describe the groups of transformations that left various properties of geometric figures invariant, and he then used these invariants to characterize the various types of geometries, an approach that constituted his so-called Erlanger Programm.[38] Thus the highly abstract algebraic idea of groups came to encompass the visual insights and logical complexities of synthetic geometry.

The transformation of geometry from being the unique science of physical space to the study of different abstract structures that might or might not apply to the natural world was a major intellectual change. The parallel development of noncommutative and even nonassociative algebras provided another instance of this same novelty. The existence of abstract systems with nonobvious or counterintuitive first principles was something new in the nineteenth century. Cantor's theory of the actual infinite was another important example. By the nineteenth century's end, the essence of mathematics was considered by many mathematicians to lie precisely in its autonomy—in the freedom of mathematicians to choose whatever systems they wanted to investigate.

VI. Probability and Statistics

The abstract ideas of symbolism also had applications that were quite down to earth. An important example is the study of probability. Probability theory began in 1654 with the correspondence between Blaise Pascal and Pierre de Fermat about problems in games of chance. Aristotle had said in his *Posterior Analytics* (I.30.87b19) that there could be "no knowledge by demonstration of chance conjunctions; for chance conjunctions exist neither by necessity or as general connections." But by appealing to what Leibniz later called the principle of sufficient reason, reinforced by the idea of "equity" used in determining what fixed sum should be paid for uncertain future benefits in contracts (Daston 18–19; Hacking 122–23), Pascal and Fermat, by treating situations that are symmetrically defined—like the chance of getting a particular number from a fair, six-sided die or getting heads or tails from a fair coin—as equally probable, were able to use combinatorial principles to develop elementary probability theory. And Christiaan Huygens systematically presented their ideas in a brief essay on probability and games of chance, *De Ratiociniis in ludo aleae*, in 1657.

In the eighteenth century, mathematicians, already impressed by the power of mathematics as applied in physics, wanted to apply probability theory to examples of uncertainty than more profound games of chance. More sophisticated mathematics, too, was at hand to help. The first major work was that of Jakob Bernoulli, with the modest title *Ars conjectandi* (1713;

Bernoulli, *Art*). He treated independent events with various probabilities, used the binomial theorem and the Pascal triangle, and developed a theory for what are now called Bernoulli trials. He also asked what would happen if we applied the theory of probability to civil, moral, and economic matters. If an outcome had high probability, say .999, he thought that it could be considered "morally certain." And the more observations one makes, he said, the greater the probability that the observed frequency of a type of event approaches the real probability of that type of event. Bernoulli used an idea like the calculus's notion of limit—that, given a sufficiently large number of observations, the difference between the real probability of a type of event and the observed frequency of events of that type can be made less than any chosen quantity—to calculate explicitly the number of observations needed for a given margin of error. For this reason, he is regarded as the originator of what is now called the law of large numbers.

Abraham De Moivre pushed these ideas further in his *Doctrine of Chances* in 1718. He calculated many probabilities using the new mathematics of infinite series and logarithms. De Moivre was the first to give the exponential function describing the binomial distribution, and he used this discovery to show how the accuracy of a probability estimate depends on the square root of the number of observations—a crucially important result in modern probability and statistics. De Moivre also applied probability theory to social questions like finding fair prices for annuities.

To use probability theory in the natural sciences, it is important to understand how close observed frequencies will be to a probability already known from mathematical calculation. But it is also important to solve the inverse problem: Given a set of observed frequencies, what is the actual probability? And how should the inferred probability be changed when more observations come along? To put it another way: probability theory allows one to mathematically consider the entire universe of observations and then to ask what the probability of a particular outcome might be. The inverse problem is, given a particular set of observations, what is true of the universe? This is the basic problem of statistical inference: given a sample, what is true of the whole?

The inverse problem was first seriously approached by Thomas Bayes, who used the mathematics developed by Bernoulli and De Moivre, as well as techniques from calculus, to attack it.[39] The standard formulation of the problem Bayes wanted to solve asks, what is the probability of an event *E* given that some set of observations, *F*, has actually happened? Reasoning from the definition of probability, he formulated the result now known as Bayes's theorem: For two events *E* and *F*, the probability of *E* given that *F* happens is given by a quotient, namely the probability of both *E* and *F* happening, divided by the probability of *F* happening alone. Bayes modeled the probabilities in such quotients by areas, and he calculated them as integrals. He gave a formula using such integrals, although the integrals could not always be calculated. Bayes's theorem has become important in the subsequent history of probability theory, and his discussion of the use of observed data to adjust one's prior ideas about probability has had great influence in the modern philosophy of science.

Another application of probability theory in the eighteenth century addressed the problem of finding the "true value" of some real-world parameter, given that all observed measurements are subject to errors. Although a successful theory of errors had to wait for the nineteenth century, men like Euler, Roger Boscovich, Legendre, and, above all, Pierre-Simon Laplace began the process of using probability theory and the techniques of the calculus to mathematically describe the pattern made by errors in observation and to minimize their effect on the conclusions of science. In 1805, Legendre suggested that the best way to deal with errors in observation is to use calculus to find the value that makes the sum of the squares of the errors a minimum. Using an eighteenth-century-style symmetry argument, Legendre said that minimizing the sum of the squares of the error would establish "a sort of equilibrium which, preventing the extremes from exerting an undue influence is very well fitted to reveal that state of the system which most nearly approaches the truth" (Katz 819). Gauss pushed this method further, using the method now called Gaussian elimination to solve the equations needed to calculate the least-squares solution, and he related the method to his new discovery of the exponential function that describes the probability of errors of given magnitudes.

Meanwhile, Laplace, using what is now called the central limit theorem, gave a different and independent derivation of the same error law. Laplace's magisterial *Analytic Theory of Probability* of 1812 brought together all the major work of the previous century in probability. Laplace also had much to say about the applications of probability to society. The use of probability, rather than certainty, in science raises important philosophical questions. For instance, do social regularities, statistically described, imply that there are constant social causes? Or do individuals even have freedom? In his *Philosophical Essay on Probabilities*, Laplace argued that the universe was subject to invariable laws, so that the need to use probabilities was only the result of human ignorance. These views were consistent with his work in celestial mechanics that argued that the various perturbations of the solar system cancelled each other out and that the solar system is stable, and with his explanation of the origin of the solar system—and the regularities that Newton had invoked God to explain—on the completely naturalistic basis of the condensation of a rotating cloud of matter. Laplace's faith in the power of reason to discover the regularities of the universe is characteristic of his time. The view that reality is in some sense essentially statistical comes late in the nineteenth century, especially through the statistical mechanics of James Clerk Maxwell.[40] Similar questions arise in the twentieth-century debates over the implications of quantum mechanics. Again, we see that technical developments within mathematics can interact with scientific and social questions and can have unexpected but highly significant effects.

VII. The French Revolution

The period of the French Revolution marked a change in the direction and pace of mathematical progress. This came in part through major developments in mathematics itself. But, perhaps in larger part, the change came through new institutional arrangements.

Mathematical education in the eighteenth century was largely a haphazard affair. Some prominent mathematicians were self-educated. Others were taught by individuals. Some were the product of Catholic schools. Later in the century and especially in France, some attended military schools. The École Polytechnique, founded as a result of the Revolution, was to change this pattern. While in England some of the motivation for teaching mathematics was to reinforce the authority of established ideas, in France the revolutionary ideology promoted the idea of educated citizens for the Republic and of careers open to the talented. The study of mathematics was especially encouraged because of its utility in engineering, architecture, and warfare. This was the case even though the mathematics faculty at the Polytechnique included men like Lagrange, Legendre, Laplace, Simon-Denis Poisson, and Cauchy, whose orientation was not primarily practical.

One way to appreciate these changes in the social context of mathematics and mathematical education is to view their playing out within the careers of a distinguished set of French mathematicians whose careers spanned the Revolution.[41] We will consider six mathematicians, in the order of their birthdates. They are Joseph-Louis Lagrange (1736–1813), the Marquis de Condorcet (1743–94), Gaspard Monge (1746–1818), Pierre-Simon Laplace (1749–1827), Adrien-Marie Legendre (1752–1833), and Lazare Carnot (1753–1823).

Lagrange learned his mathematics first from the Abbé Beccaria at the College of Turin but then through his own reading and thinking as well as his correspondence with Giulio Fagnano and with Euler. He taught at the military school in Turin, which is where he first took up the problem of the foundations of the calculus. He was involved in founding the scientific academy at Turin but then, at d'Alembert's recommendation, replaced Euler at the court of Frederick the Great in Berlin. Hoping for some peace and quiet after Frederick's death, which unfortunately he did not get, he moved to Paris in 1788. After the Revolution, Lagrange was pressed into service at the Polytechnique, and there he delivered the lectures that became his *Theory of Analytic Functions* (1797), the first of the great tradition of the French *Cours d'analyse.*

Condorcet was educated first at the Jesuit College at Reims, and then at the Collège de Navarre and then the Collège Mazarin in Paris. His research included not only calculus and probability but also the application of mathematical methods to voting theory. During the Revolution he sided with the Girondists; the Jacobins had him arrested, and he died in prison.

Monge's education began at the Oratorian College in Beaune and continued at the Collège de la Trinité in Lyons and then at an engineering school, the Ecole Royale at Mézières.

He later taught at Mézières for many years. Monge was a major player during the Revolution; for a time he was minister of the navy, and he later went to Egypt with Napoleon. Monge was also one of the prime movers of the Ecole Polytechnique, where his emphasis on descriptive geometry revived three-dimensional geometry in France.

Laplace began his education at a Benedictine priory school in Beaumont-en-Auge and then entered the university at Caen to study theology. His mathematical abilities attracted the patronage of d'Alembert, so Laplace got a job at the Ecole Militaire in Paris. Eventually he entered the Académie des Sciences and the Bureau des Longitudes before joining the faculty at the newly established Ecole Polytechnique.

Legendre began his education at the Collège Mazarin in Paris and then, as recommended by d'Alembert, taught at the Ecole Militaire in Paris. Legendre's research career took off when he won the 1782 prize of the Berlin Academy for a paper on projectile motion. He followed Laplace into the Académie des Sciences in Paris, doing important work in geometry and elliptic functions as well as number theory.

Finally, Lazare Carnot had been Monge's student at Mézières. A distinguished contributor both to geometry and to the foundations of the calculus, Carnot became prominent during the Revolution. He was a member of the Committee on Public Safety and was lauded as "Organizer of the Victory." Later championing Napoleon, he too was exiled after Waterloo. He helped his son Sadi Carnot, after whom the Carnot cycle is named, in questions about thermodynamics.

The careers of these men illustrate first the old origins, education, and means of support for mathematicians and then the new social standing and social roles that began after the Revolution. "The advancement and perfection of mathematics," said

Napoleon, "are intimately connected with the prosperity of the State."[42] And the State was connected also to the advancement of mathematicians. The post-Revolutionary generation of French mathematicians would largely be graduates of the *Polytechnique.*

Another byproduct of the Polytechnique was the first mathematical periodical, the *Journal de l'école polytechnique*, founded in 1794. The second mathematical periodical, also French, was the *Annales des mathématiques pures et appliquées*, founded in 1810 by Joseph Gergonne, an artillery officer who had been a student at the *Polytechnique.* These periodicals inspired August Leopold Crelle in 1826 to found the most successful of the three, the *Journal für die reine und angewandte Mathematik.* Crelle's journal brought Abel's work to wider European attention, published significant papers by Dirichlet, and generally helped put German mathematics on the world map. To round out the international journal picture, we observe that the important French *Journal de Mathématiques Pures et Appliquées* was founded in 1836 by Joseph Liouville and, in 1837 in England, the *Cambridge Mathematics Journal*, which eventually became the better-known *Quarterly Journal of Pure and Applied Mathematics,* was founded.

Among the other public roles for mathematics stemming from the Revolution was the establishment of the metric system. The older weights and measures systems could not claim the sanction of reason. Measures of length, area, weight, and volume varied from locality to locality, often being subject to argument and negotiation even in an individual place.[43] The Académie des Sciences set up the committee that devised a system of weights and measurements consistent with the decimal number system. The goal was not just standardization but the relation of basic units to phenomena in nature in a rational way. This required the expertise of mathematicians.

This period also saw a wealth of new textbooks. Lectures on algebra, analytic geometry, and calculus at the Polytechnique were converted into highly influential texts. For instance, Silvestre F. Lacroix, who succeeded Lagrange as professor of analysis at the Polytechnique in 1799, wrote a text on analytic geometry that appeared in twenty-four further French editions in the century following its publication, and his textbooks on arithmetic, algebra, geometry, and calculus were similarly successful. Through translations, French textbooks became highly influential outside of France as well as within it. For instance, Lacroix wrote a short calculus text in 1802 which, since it was translated into English by three mathematically talented Cambridge University students, Charles Babbage, George Peacock, and John Herschel, played a key role in bringing the Continental approach to mathematics into England. Legendre's geometry, as translated in 1834 at West Point by Charles Davies, became a classic American university text. Lacroix also published a three-volume encyclopedic text on the calculus in 1797, which appeared in a second edition in 1810–1819. This larger work by Lacroix was essentially a compilation of all the important advanced work on the calculus of the eighteenth century. He said he was trying to help those who, not privileged to live in Paris, might be unable to consult all the original papers in the proceedings of various eighteenth-century scientific academies. This compendium was a gold mine for its later readers, which included Cauchy.

Even after the death of Lagrange, Lacroix, Monge, and Laplace, the Polytechnique continued to host prominent mathematicians and mathematical physicists on its faculty, including Siméon Denis Poisson, André-Marie Ampère, and Cauchy. The Polytechnique also served as a model for scientific and technical institutions in other countries. But mathematics was about to take on a larger role in traditional universities as well.

Mathematics around 1800 marks the beginning of the career of Carl Friedrich Gauss (1777–1855), who is on most people's short list of the greatest mathematicians in history. For our purposes, Gauss's work exemplifies the nature of the transition between eighteenth-century mathematics and that of the nineteenth. Committed to the spirit of Greek geometrical rigor, he also thought numerically and algebraically. Thus, he personified the extension of Euclidean rigor to modern algebra and analysis. He was especially important in midwifing the transition from particular algebraic problems to abstract algebra. But he also helped work out the foundations of complex analysis, to develop and promote the analytic theory of probability, and to push geometry toward a more sophisticated set of foundations beyond the Euclidean model. And his career marks the beginning of what was to become the central role of German universities in the history of modern mathematics.

Gauss grew up in the city of Brunswick, which was beginning to revive economically in the latter part of the eighteenth century. The talented son of parents of modest means, Gauss had his ability recognized while a pupil at the Collegium Carolinum. He eventually enjoyed the patronage of the Duke of Brunswick-Wolfenbüttel, thus he benefited from the old feudal order. Gauss pursued his advanced studies at the relatively new university at Göttingen, perhaps choosing it for its orientation toward the sciences. Among his university friends was Wolfgang Bolyai, the father of Janos. At Göttingen Gauss was introduced to algebra and number theory by the mathematician Abraham Gotthelf Kästner, although he had much more admiration for another of his professors, the physicist Georg Christoph Lichtenberg. Gauss made extensive use of the university's good library as he taught himself more advanced mathematics.

But Gauss went considerably beyond his predecessors. In the case of number theory, he gave what is now the accepted definition of congruence of integers relative to a modulus (x is congruent to y modulo m if m divides the integer $x-y$)[44]; the notation he introduced for congruence is still used today. He proved a wealth of results about congruences, including residues of powers and primitive roots modulo p. Gauss gave six different proofs for the law of quadratic reciprocity, and extended the idea of the integer to the so-called Gaussian integers, defining what it meant for them to be "prime"—and, incidentally, providing a logical foundation for complex numbers in terms of pairs of real ones. In 1848, in the last of the four proofs he published for the fundamental theorem of algebra, he also gave a geometric interpretation to this idea of complex numbers. Although others—Caspar Wessel, Jean-Robert Argand—had made similar suggestions, it was through Gauss's work that the mathematicians at large came to accept this now-standard view of complex numbers.[45]

Addressing the question of solvability of equations in algebra, Gauss focused on the so-called cyclotomic equations of the form $x^n - 1 = 0$. Having established the solvability of such equations and characterizing their solutions, he showed that if n is a prime and n-1 is a power of 2, the equation can be solved in radicals, that is, solved entirely by means of the four basic arithmetical operations and taking roots. One consequence he drew is geometric: the polygons that can be constructed with compass and straightedge are those that have a number of sides that is any multiple of two times a prime of the form $2^k + 1$—those now known are 3, 5, 17, 257, and 65,537.

Gauss also addressed the algebraic study of quadratic forms: functions of two variables of the form $ax^2 + 2bxy + cy^2$. For instance, he treated linear functions of two new variables substituted into the original quadratic form, focusing on the matrix of the coefficients of those linear functions. He wrote these coefficients in a rectangular array and worked out the "composition," or product, of two such substitutions, foreshadowing the abstract idea of matrices. He defined two quadratic forms as equivalent when there was a linear substitution that transformed one into the other; two such forms have the same discriminant. Gauss investigated the properties of composition of such forms as an operation on the classes of equivalent forms: the operation is both commutative and associative. Gauss observed that his proofs of results about these classes resembled his proofs about powers of residue classes, a fact which suggested many results in what later became the study of commutative groups.

In analysis, Gauss used his ideas about complex numbers in the theory of functions of a complex variable. He anticipated (though he did not publish) the Cauchy integral theorem, explaining his ideas in a letter to Friedrich Wilhelm Bessel. Starting from the work on surface integrals by Lagrange in the second edition of the *Analytical Mechanics*, Gauss used such integrals to find the gravitational attraction of an elliptical spheroid, treating the integrals parametrically. Gauss also used these integrals to prove special cases of what now is known as the divergence theorem.

In probability theory, Gauss's method of least squares for dealing with multiple observations was applied by Bessel to measurements of hundreds of star positions. Gauss's theory worked well: the distribution of actual errors in measurements closely followed Gauss's exponential error function. Another famous application was Gauss's calculation of the orbit of Ceres, the first asteroid to be discovered, using only the existing observations without prior assumptions about the shape of the orbit.[46]

In geometry, Gauss was both a practitioner and a theorist. He was especially interested in geodesy, leading the geodetic survey of Hanover in the early 1820s. He wrote a major book on the geometry of curved surfaces in which he developed the conditions for conformal mapping, and focused especially on the property of curvature of surfaces. He gave an analytic characterization of curvature of a surface at a point, proved major theorems about curvature, and pioneered treating surfaces in terms of their intrinsic local geometry—a point of view important later in Riemann's development of the theory of manifolds. Finally, when he was asked to choose a topic for Riemann's inaugural lecture from a list Riemann had submitted, Gauss chose the foundations of geometry and thereby encouraged Riemann's great contributions to the subject (Gray, *Ideas* 129).

Politically, Gauss's conservatism and Hanoverian nationalism won him patronage and helped motivate his work on geodesy, magnetic surveys, and astronomical work at the observatory at Göttingen. But his distaste for revolutionary ideas and for Napoleon's armies discouraged any significant communication with the mathematical trendsetters in France, to the mathematical detriment of both sides.

Gauss may have viewed himself more as a systematizer and solver of problems than as an opener of new paths. But the rigor, precision, and, above all, generality of his results laid the basis for many new departures. In this respect he epitomizes the nature of mathematics in the early nineteenth century. And he certainly helped jump-start the nineteenth-century shift of the center of mathematical action in the direction of Germany. His students and close associates at Göttingen compose a distinguished list, one that includes Bessel, Richard Dedekind, Christoph Gudermann, Johann Benedict Listing, Bernhard Riemann, August Möbius, and Christian von Staudt.

The revival of mathematics at German universities in the early nineteenth century was not, of course, wholly the doing of Gauss. Other key figures in this regard were Bessel, Franz

Neumann, and Carl Gustav Jacobi. Bessel's chief work was in mathematical astronomy; modern mathematicians know him because, while studying the series expansions necessary to calculate the perturbations of planetary orbits, he introduced what are now called Bessel functions. It was Gauss who recognized Bessel's talent; Bessel took his doctorate from Göttingen, at Gauss's recommendation, and then worked at the observatory at Königsberg. Neumann, who entered the University of Berlin in 1817, studied briefly afterward at Jena and then returned to Berlin for his 1825 doctorate. Neumann then went on to teach at Königsberg, holding the chair of physics and mineralogy but having several mathematicians among his students, the best known being Rudolf Clebsch.

As for Jacobi, he entered the University of Berlin in 1821 but found the level of mathematical instruction too low and turned instead to reading the works of various leading mathematicians, mostly French. Jacobi too began his career at Königsberg, where he taught for eighteen years. He gained special fame for his classic work on the theory of elliptic functions (Birkhoff 204–24). He is known also for work in number theory, differential equations, determinants, and the theory of rotating liquid masses. Jacobi's students and young associates included Carl Wilhelm Borchardt, Eduard Heine, Ludwig Otto Hesse, Friedrich Julius Richelot, Johann Georg Rosenhain, and Phillip Ludwig von Seidel—again, a distinguished group. Jacobi linked his teaching with his research and inaugurated something that was then quite novel in mathematics: research seminars that attracted advanced students and colleagues alike.

Mathematical research continued and grew throughout the nineteenth century. Especially important was the University of Berlin, where the school of Weierstrass dominated analysis in the second half of the century. But pure, abstract mathematics grew internationally: in Britain, with figures like Arthur Cayley and James Joseph Sylvester; in Russia, with people like Mikhail Ostrogradsky, Pafnuty Chebyshev, and the first woman to earn a doctorate in mathematics (under Weierstrass's direction in Germany), Sofya Kovalevskaya; in Italy, with Luigi Cremona and Eugenio Beltrami; and in the United States, with Benjamin Peirce and Josiah Willard Gibbs, and where the founding of Johns Hopkins University in 1876 brought the model of the research university in general, and the mathematical seminar in particular, to the New World under Hopkins's first mathematics chair, J. J. Sylvester. And of course the French tradition continued with men like Gabriel Lamé, Joseph Liouville, and Charles Hermite, *polytechniciens* all. The fact that by the 1870s excellent research was being done at so many centers is one more piece of evidence for how mathematics flourished in the nineteenth century.

Conclusion

Our survey has revealed how mathematics, this supposedly independent and abstract subject, was influenced by, and had influence upon, other fields. But we must reiterate our view that, although the story of mathematics from 1591 to the 1830s is related to the parallel stories of science, art, philosophy, and society, it is also a story with its own internal dynamic. Let us look again at our whole story and discuss a little about what it has come to mean since.

In the eighteenth century, mathematics was seen as the study of the realm of quantity. That realm was further divided into the study of number and the study of space. The study of number in general could focus on the finite, as in algebra, or on the infinite, as in analysis—or space and the visual could be emphasized, as they were in synthetic geometry. Still, all of these subjects were believed to fit together into one consistent whole, one that included the physical world. The space that geometry was about was the space of Newtonian physics: absolute, infinite, isotropic, symmetric, and therefore Euclidean. Symmetry principles, like that of sufficient reason, permeated not only geometry but also probability theory, science, and philosophy.

The eighteenth century celebrated the power of mathematics to make sense of the natural and social worlds in other ways as well. First, mathematics was a model of reasoning, both because of its obeisance to the ancient Euclidean deductive model and because its new symbolic language was an instrument at once of discovery and of verification. The "probability of judgments" that suggested to Laplace and Poisson that human judges could be replaced by probability models, and the new voting theory of Condorcet and Jean-Charles de Borda, shared in the prestige of other applied mathematics, from the predicted return of Halley's comet in 1758 to Laplace's mathematical demonstration of the stability of the solar system.

In the first part of the nineteenth century, this began to change, though not all at once. Much of what was new emerged from attempts to solve particular problems posed by eighteenth-century mathematics. This trend is exemplified by the creation of new abstract concepts to solve existing problems in algebra and number theory, the extension of ideas from geometry and calculus to more than two dimensions, and even the rigorization of analysis.

As Jeremy Gray has recently argued, though, even in the apparently abstract new foundations of analysis of Cauchy, there are unspoken realist assumptions (Gray, *Plato's Ghost* 65). Cauchy had an underlying intuition about real numbers and often took some of their properties for granted. In the case of Hamilton's invention of a noncommutative algebra, the realist assumption was explicit. Even Lobachevsky, in his non-Euclidean geometry, wanted to address questions about the nature of real space. The fact that Kummer's discovery of integer-like objects that had nonunique factorization came as such a surprise helps reveal the widespread faith that the objects of mathematics, however abstract and diverse they had become in the 1830s, still formed a consistent and intuitively understandable set.

As the nineteenth century proceeded, though, mathematics moved toward even greater generality and abstraction. At the same time, mathematics, newly autonomous intellectually, setting its own problems and insisting on its own unique standards of rigor, was also becoming a profession established in universities throughout Europe and, eventually, all over the world. Journals and societies devoted solely to the advancement of mathematics were founded. The freedom of mathematical choice came to the fore. By 1900, one could argue that all of this had cut mathematics off from not only the world of applications but the world of intuition as well. Mathematics had become so free and independent that its applicability to the world then was becoming a serious problem for philosophy. This situation produced a new agenda for the twentieth century, including the search for proofs that all of mathematics is consistent[47] and that reasoning about infinite sets is legitimate. And all of this raised new philosophical and psychological questions about the nature and limitations of human thought.

In 1800, none of this had yet happened. But by focusing on the development of mathematics from the eighteenth century to the 1830s, we have had a ringside seat for a crucial set of changes from the mathematics embedded in the unified world view of the Enlightenment to the diverse, abstract, professional, and powerful mathematics of the nineteenth century. Furthermore, the importance of mathematics for science and for modern culture in general has meant that all major thinkers had at least to talk about it, even when they did not grapple with the latest mathematical ideas and their implications. So, even though the relationship of mathematics and culture may be complex and idiosyncratic, our understanding of the philosophy, science, and art of an epoch can and should be enriched by an understanding of its mathematics as well.

Notes

1. For summaries of all these developments, the best general histories are Katz, *A History of Mathematics*, and Boyer-Merzbach, *The History of Mathematics*. For the classic account of the nineteenth century by a major contributor to its mathematics, see F. Klein, *Vorlesungen*.

2. This point is worth illustrating. To do so, we will use slightly more modern notation than Vieta's. After his innovation, the equations $x2 + 10x = 39$ and $x2 = 5x - 6$ ceased to be thought of as different, since both are examples of $ax2 + bx + c = 0$ $(a \neq 0)$, which represents every possible quadratic equation. Solving that general equation by the technique of completing the square yields the quadratic formula $x = (-b \pm \sqrt{[b2 - 4ac]}) / 2a$. That formula is the general solution, and it makes manifest exactly how that solution depends on the coefficients.

3. For example, suppose an equation has exactly two roots, $x = c$ and $x = d$. Clearly $x - c = 0$, $x - d = 0$, and therefore the product $(x - c)(x - d) = 0$. Multiplying this product out yields the quadratic equation $x^2 - (c+d)x + cd = 0$. The form of that quadratic itself suffices to show that a quadratic has at most two roots, that the constant term must be the product of the roots, and that the coefficient of the linear term is the sum of the roots with the sign changed.

4. Whenever selected original texts are available in Struik's *Source Book*, I provide a reference to that work. As a bonus, the reader will find Struik's excellent historical and mathematical commentary on these texts. For a full account of Vieta's work and historical background, see J. Klein, *Greek Mathematical Thought*.

5. See especially Boyer; Mahoney; and Bos.

6. See Whiteside, vol. 1, especially vii–xix; Struik, *Source Book* 270–84; Hofmann; and Katz 543–575.

7. Compare Katz 608–611.

8. For Agnesi's career in social context, see Mazzotti.

9. See Grabiner, "Was Newton's Calculus"; and Sageng.

10. Euler's derivation is beautifully presented and explained in Dunham 86–102; for a translation of the key texts, see Struik, *Source Book* 345–357.

11. See Koppelman.

12. For excerpts, see Struik, *Source Book* 333–38. For a discussion, see, e.g., Grabiner, 26–27, 34; and Cajori.

13. For MacLaurin, see *Treatise of Fluxions*, vol. 1; compare Grabiner, "Was Newton's Calculus"; and Sageng. For d'Alembert, see Struik, *Source Book* 341–55. For Carnot, see Gillispie, *Lazare Carnot*.

14. For Lagrange's philosophy of foundations, see his *Théorie*, especially the title page; and Grabiner, *Historian* 11–15; for his delta-epsilon proofs and an assessment of them, see Grabiner, *Origins*, esp. 122–27.

15. For Cauchy's lectures, see his *Cours*. For excerpts, see Birkhoff 1–10; for a discussion, see Grabiner, *Origins* 132–38.

16. Actually, several of Cauchy's proofs, including this one, assume the function to be uniformly continuous, and his proofs about limits in the 1820s often conflate the modern concepts of pointwise convergence and uniform convergence. It would take a few more decades to sort this all out, as we shall indicate a bit later on.

17. For Cauchy, see *Cours* 378–80. For Bolzano, see "Translation."

18. See Grabiner, *Origins* 24–25.

19. For Riemann, see Birkhoff 16–23.

20. See Struik, *Source Book* 81–87.

21. Reprinted in Whiteside, vol. 2.

22. Lagrange, "Réflexions," excerpts in Struik, *Source Book* 102–11.

23. On all of this, see Van der Waerden, esp. 76–88, 103–12, and 137–54.

24. See Pycior.

25. Quaternions somewhat resemble the complex numbers, but instead of the basis being the number 1 and i such that $i^2 = -1$, the basis for the quaternions is composed of 1, i, j, and k, such that $i^2 = j^2 = k^2 = -1$ and where $ij = -ji$, $ik = -ki$, and $jk = -kj$.

26. See Hankins.

27. For Euler, see Struik, *Source Book* 36–40. For Germain's number theory,

see Katz 714–15.

28. A whole number has a "residue" of *k* modulo *n* when dividing the number by *n* gives a remainder of *k*. Numbers with the same residue modulo *n* are said to belong to the same residue class.

29. Quadratic residues are numbers whose square falls into a particular residue class. For instance, if there is an integer *k* such that dividing k^2 by *n* leaves a remainder of *q*, *q* is said to be a quadratic residue modulo *n*. For Euler's work on these, see Struik, *Source Book* 40–46. For Legendre's further work on the law of quadratic reciprocity, see Struik, *Source Book* 49–54.

30. For Euler's work on this, see Yushkevich; for Riemann, see Birkhoff 93–98.

31. For a full account of his career, see Taton.

32. Euclid's postulate states that, if a straight line falling on two straight lines makes the interior angles on the same side less than two right angles, then the two straight lines, if produced indefinitely, meet on that side where the angles are less than two right angles.

33. For a good account of these inventions, see Gray, *Ideas* 83–128.

34. See Gray, 122–23; compare Bonola, which includes the texts of Bolyai's and Lobachevsky's work.

35. For Helmholtz and Clifford, see Richards, *Mathematical Visions* 76–114; Richards, "Geometric Tradition"; and Helmholtz. For twentieth-century non-Euclidean ideas in art, see Henderson; for physics, see Gray, *Ideas* 210–16.

36. For details, see Field; Kemp; Andersen; and Field and Gray.

37. For a good historical account of projective geometry, see Richards, *Mathematical Visions* 117–58; compare Katz 852–58.

38. For a good brief account, see Boyer and Merzbach 612–13.

39. See Bayes; and compare Katz 651–54.

40. See Porter, *Rise*, esp. 151–92; and compare Porter, "Statistics."

41. I owe this approach, though not the details, to the discussion in Boyer and Merzbach 523–52.

42. Quoted, with no source given, in Boyer and Merzbach 523.

43. A fascinating account is given by Kula.

44. For Gauss's four proofs of the fundamental theorem, see Van der Waerden 94–102; on Gauss in general, see May 298-315; and Bühler; to view Gauss's seminal work on number theory and algebra directly, see Gauss.

45. See Bühler 46.

46. Kurt Gödel proved in 1931 that this couldn't be done.

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Goethe's *Wahlverwandtschaften* and Contemporary Physics around 1800

HELMUT HÜHN

> *There are more things in heaven and earth . . .*
> *Than are dreamt of in your philosophy.*
> —*Shakespeare, Hamlet*

> *Je n'enseigne point, je raconte.*
> —*Michel de Montaigne, Essais*

The following analysis of Goethe's *Wahlverwandtschaften* (*Elective Affinities*) attempts to investigate and sketch his understanding of physics around 1800. By employing a poetical language of forms that has fascinated readers for over two hundred years, the novel manages to connect the study of nature, history of science, reflections on art, and social analysis. The purpose of the present interpretation is to explore this complexity and bring it to bear. What is Goethe's knowledge of natural science at this time? What is his method of inquiry? What, for Goethe, is the constellation of the study of nature, philosophy, and art? What are Goethe's fundamental approaches as a critic of epistemology, language, and science? How does he situate himself within the intellectual movements of his time, in relation to the context and nexus of contemporary discourse? What experiences from the study of nature are transformed into poetic form, and what insights gained from aesthetics influenced his naturalist studies? The years 1806 to 1809 are central to the following preliminary presentation, which is designed to proceed in a "spiral movement"[1] that will precisely illustrate and clarify the transfer between the study of nature and art as well as their complex interrelationship. With reference to his work on *Wahlverwandtschaften*, Goethe's relationship to the emerging natural sciences as well as to the romantic and idealistic study of nature can be more closely illuminated.

1. His continued works on physics, as Goethe emphasized in his announcement of the work, suggested the strange title (*seltsamen Titel*).[2] The novel itself is intimately tied to these studies. In his collaborative *Lectures on Physics* (*Physikalische Vorträge*) with the physicist Thomas Seebeck, which immediately preceded the conception of the novel, Goethe had developed the concepts of polarity (*Polarität*) and progression (*Steigerung*). These lectures are based on the phenomena of magnetism, which Goethe understood as elementary[3] (to use a concept from the era of the *Wahlverwandtschaften*, or "*die Epoche der Wahlverwandtschaften*"),[4] and which he conceived of as an "Urphänomen."[5] The magnet conveys the perception of polarity, of positive and negative, of attraction and repulsion. In the lectures these perceptions of polarity were transferred onto the other areas: electricity, chemistry, optics (Pörksen 295). Goethe was particularly fascinated with the new phenomena of chemical electricity and electrolysis, which had been made public by the Englishman Humphry Davy. Amid the recorded keywords to the *Physikalische Vorträge* for April 6, 1808, his text says "Romanen Motive" ("motifs for novels"; MA 9:921).[6] Thus, on April 11, a few days before the first schematization of the

planned novel, Goethe had given thought not only to the phenomenal realm of the powers of natural attraction and repulsion but also to the motives in the novel that could arise out of this context.

2. With the title of the novel and his announcement, the author places the relation of the study of nature and poetry as well as the conflict of natural necessity and the autonomy of reason into the center of attention. This can be seen as an attempt to influence the reception of his work. From the very beginning, the focal point for the reader is the relation of chemistry and literature. Nevertheless, caution is advised. Interpretations of the novel that reduce the work of art to a generative principle have not done justice to it, as can be amply illustrated in historical and critical analyses.[7] The attempts based on deciphering the constellations and narrative structure of the novel only by recourse to the famous talk about elective affinities in the fourth chapter of the first part,[8] will remain more or less unsuccessful.[9]

3. The poetic retranslation of the chemical model in the *Wahlverwandtschaft* into the realm of interpersonal and social relations is restricted to a small part of the poetic transformation of science that characterizes this novel. If one further expands the focus beyond the thematized art of the chemical separation and connection, it becomes apparent that the author has poeticized the complete knowledge of available science and art in his novel. One can describe—with Christoph Martin Wieland—the almost encyclopaedic form of the novel as attributable to his "desire to write an instructional novel" ("Begierde einen Lehrreichen Roman zu schreiben"), which, according to Wieland, compelled the author

> . . . .beinahe alle Künste und Wissenschaften zur Mitleidenheit zu ziehen; und die sämmtlichen Mode-Studien unsrer Zeit, die Naturwissenschaft, die Botanik, die Gartenkunst, die Chemie,

> die Baukunst, die Decorationskunst, die Kunst Gemählde durch Mimik darzustellen, und Gott weiß was noch für schöne Künste, haben das ihrige reichlich beigetragen. (Härtl 158)[10]
>
> . . . to broach the issues of nearly all arts and sciences; and the contemporary fashionable research, the natural science, botany, landscape design, chemistry, architecture, interior design, the *tableau vivant,* and God knows what other fine arts have contributed to the project.

One could also ask why and in which manner Goethe integrated contemporary science—be it theory of art, aesthetics, medicine, economics, philosophy, law, pedagogy, history, geography, or contemporary natural science—into the novel. Did he want to write an educational novel (*Lehrreicher Roman*)? Did he want to combine the narrative in a significant way similar to the Horatian dictum *delectare et prodesse*? Could he only legitimate the story of the novel by the mediation of science? Did he want to compose a modern epic of his time and weave into it "what is significant and special in the particular historical moment" ("was die Zeit Bedeutendes und Besonderes hat")?[11] Had specialized knowledge become so fragmented and nondescriptive that it could only be reconceived and recreated in a narrative that is meaningful and provides guidance? What binds and holds together the elements of the narrative in Goethe's novel?

4. In the era of the *Wahlverwandtschaften*, Goethe thought of himself as both a poet *and* a naturalist who accompany each other. In Goethe's own understanding, both of the great projects at this time, the scientific *Farbenlehre* and the literary *Wahlverwandtschaften*, belong closely together.[12] He even mentioned to Karl Friedrich von Reinhard, one of the most important

correspondents at this time, that the *Wahlverwandtschaften* are the first "part of the colour theory" ("Theil des Farbenwesens").[13] Although this was already acknowledged in the early history of the reception of the novel,[14] it still needs a more thorough investigation.

5. Because the empirical sciences emerge from the given metaphysical system of knowledge, the separation of physics and metaphysics is relevant not only for Goethe's self-understanding as a naturalist. The new dynamics of the empirical sciences around 1800 and their rapid proliferation—Goethe refers in his correspondence with Schiller to the "hydra with a million heads" ("millionfache Hydra der Empirie")[15]—result in modifying the classical Aristotelian notion of science.[16] Aristotle understood science as knowledge based on principles or basic propositions. It was understood as a categorical deductive system of knowledge that can be characterised in its most concise form through the determinations of universality, necessity, and truth. With the increasing success of the empirical sciences, the established hierarchy in philosophy of *a priori* reasoning and empirical knowledge of facts was gradually abolished.

6. In the *Farbenlehre*, Goethe clearly and strikingly emphasizes the different *modi operandi* of the physicist and philosopher:

> Man kann von dem Physiker nicht fordern, daß er Philosoph sei; aber man kann von ihm erwarten, daß er so viel philosophische Bildung habe, um sich gründlich von der Welt zu unterscheiden und mit ihr wieder im höhern Sinne zusammenzutreten. Er soll sich eine Methode bilden, die dem Anschauen gemäß ist; er soll sich hüten, das Anschauen in Begriffe, den Begriff in Worte zu verwandeln, und mit diesen Worten, als wären's Ge-

> genstände, umzugehen und zu verfahren; er soll von den Bemühungen des Philosophen Kenntnis haben, um die Phänomene bis an die philosophische Region hinanzuführen. (FA1 23.1:232)[17]

> One cannot ask the physicist to be a philosopher; but one can expect from him a certain philosophical knowledge that separates him from the world but also connects him again in a higher sense. He has to construct a methodology that is suitable for observation; but he has to be careful to translate observations into concepts and concepts into words and to treat these words as if they were objects; he should have knowledge of the efforts of the philosopher to develop phenomena to reach the philosophical realm.

Let me emphasize the main point: Goethe understands himself as a physicist and *not* as a philosopher.[18] His interest is directed to the phenomena and their manifestations. He seeks a language that corresponds to the manifestation of the phenomena and preserves the perception of the phenomena. Although Goethe's intention is to connect the naturalist's understanding of phenomena with philosophy, he categorically distances himself from philosophical speculation. He wishes to retain a vital intuition that cannot be substituted and must act as a corrective instance for any precipitant formation of imagination and theory. He aims toward a "higher"—that is, sublimating—intuition, toward an intuition of transitory phenomena perceived through the eyes of a reconstituting spirit.[19]

7. As a naturalist, Goethe was interested in the philosophical discourse of his times. First and foremost he hoped that *methodological* insights would emerge from any philosophical

controversy, something that the naturalist can implement and, at the same time, the intuitive paths that he had trodden, could procedurally lead to methodical certitude, criticism and explanation. Throughout his life Goethe remained sceptical of the conceptual discourses' autonomy, which he identified as philosophical controversy. In the era of the *Wahlverwandtschaften*, Goethe did not particularly appreciate the conceptual work of philosophy or its efforts toward honing conceptual instruments. He polemicized against it because, in the first instance, he saw in conceptual work an abstractive diminution of phenomena. It remains unclear as to what extent philosophy could be trusted with the role of epistemological comprehension. According to Goethe, one can only recognize *Urphenomena*. Every *Urphenomenon* constituted the limitations of man's knowledge. It is art that stands in for philosophy: only in art can *Urphenomena* become language.

8. Although in the era of the *Wahlverwandtschaften* Goethe recognized the limits of morphology, he understood himself as a morphologist. Morphology attempts to realize a form of thought and knowledge that neither fixates the phenomena nor erects connections between them, delivers tensions, compares shapes, or construes transitions in the mind. Morphology as a doctrine of shape and transformation, as well as experience and appropriation of the world, aims toward a synopsis of perceptions, a "clearly arranged presentation"[20] ("*übersichtliche Darstellung*") of the phenomena as a sequential development, but not toward a causal explanation of phenomena. Goethe understood morphology as a "new science" ("neue Wissenschaft") not yet established, one that "only wants to represent and not explain" [LA1 10:140]).

9. The narrative of the novel is permeated by a morphological way of thought. It is part of the essence of phenomena ("Phänomenalität von Phänomenen") that they "never appear in a

single space of representation but always in a series of sequential spaces that mirror each other and are defined by the tension between each other" ("niemals in einem einzigen Darstellungsraum, sondern stets in einer ganzen Flucht hintereinander geschalteter [sich] ineinander spiegelnder und zueinander in Spannung stehender Darstellungsräume zum Vorschein kommen"; Picht 456). According to this model, the novel constructs a complex web of connections of poetic references and reflections that are embedded in the narrative. The reader takes on the role of those who study the phenomena; he himself must create their connections.[21] Much like the naturalist, he is invited to perceive the individual facts, see the connections, and fashion the intermediate links.

10. In the era of the *Wahlverwandtschaften*, Goethe took a critical stance against the contemporary research in the natural sciences and the philosophy of nature. This is true for the empiricism of natural sciences as well as for the romantic or idealistic notions about nature, although he participated in both in various ways.[22] An important factor is "the thinking about language" ("das Sprachdenken"): Goethe consciously reflected on the relations of the study of nature and language. At this point in time, he assumed a position that was fundamentally sceptical of language. Between the word and the thing, between signifier and signified, there exists a principal divide: "we can neither express through words the objects nor ourselves" ("durch Worte sprechen wir weder die Gegenstände noch uns selbst völlig aus"; [WA2 11:167]).[23]

11. As the following letter to Wilhelm von Humboldt, dated August 22, 1806, reveals, Goethe critically scrutinizes the linguistic presentation not only of physical sciences:

> Die Formeln der Mathematik, der reinen und angewandten, der Astronomie, Cosmologie, Geologie,

> Physik, Chemie, Naturgeschichte, der Sittlichkeit, Religion und Mystik werden alle durcheinander in die Masse der metaphorischen Sprache eingeknetet, oft mit gutem und großem Sinne genutzt; aber das Ansehen bleibt immer barbarisch . . . sehr üble Folgen, daß man das Symbol, das eine Annäherung andeutet, statt der Sache setzt . . . und sich auf diesem Wege aus der Darstellung in Gleichnißreden verliert. (Pörksen 297n41)

> The mathematical formulas, the pure and applied astronomy, cosmology, geology, physics, chemistry, natural history, ethics, religion and mysticism are all dispersed into the mass of metaphorical language and often used with good and great sense; but the reputation is always barbaric . . . and has dire consequences when the symbol, which means approximation, stands for the thing itself . . . and becomes an analogy instead of a representation.

It is not only a matter of critiquing abbreviated scientific formulae or the scientific translations and allegories that go beyond established boundaries; Goethe lamented the dissolution of the epistemological difference between symbol and thing—a charge directed at Henrich Steffens's work *Grundzüge der philosophischen Naturwissenschaft*, published in 1806. He saw in this a tendency within the romantic study of nature that reveals a deficit of scientific self-reflection. Goethe's experiments are undoubtedly indebted to Kant's critical enterprise; it is his intent to expose the epistemological limits of the study of nature and also to confess "all our knowledge is symbolic" ("alle unsere Erkenntnis ist symbolisch"). Science appears to him as "*artificial* life, merged miraculously out of fact, symbol, allegory" ("künstliches Leben, aus

Tatsache, Symbol, Gleichnis wunderbar zusammengeflossen").[24] Goethe considered the conscious isolation of individual phenomena misleading and counterproductive. Yet he did not work at the analytical separation of the "miraculously merged" as defined by the pure sciences. The question arises, what concept of "fact" had Goethe used in his conversations at that time? Facts do not allow themselves to be established by the knowing subject, independent of interpretative forms or of the "modes of representation" (*Vorstellungsarten*).

12. The chemical discourse of the novel articulates both in an artistic way: a critical position toward linguistic hypostasis and ambivalence, as well as a sceptical position toward discursive propositional speech. In the maxims from Ottilie's diary, we additionally hear what sound like positions sceptical of communication:

> Niemand würde viel in Gesellschaften sprechen, wenn er sich bewußt wäre, wie oft er die andern mißversteht.
>
> Man verändert fremde Reden beim Wiederholen wohl nur darum so sehr, weil man sie nicht verstanden hat.
>
> . . . Jedes ausgesprochene Wort erregt den Gegensinn. (FA I 8:419)
>
> No one would talk a lot in society if he were conscious about the fact how often he misunderstands the other.
>
> One changes the other's speech when one repeats it mostly because one did not understand it.
>
> . . . Every spoken word evokes its opposite meaning.

13. As early as 1796 Goethe had critically reflected upon the idea of the title of *Wahlverwandtschaften*—the *attractio electiva*—as an anthropomorphic mode of speech and thought. The

concept describes the reaction of chemical substances that give up an old connection and, on the basis of a "closer affinity" ("nähere Verwandtschaft"), pursue a connection with a new substance. In 1796, Goethe had already noted reservations about the "human" way of thought that was attributed to the substances when he was endowed with "the honour of the choice in such affinities" ("die Ehre einer Wahl bei solchen Verwandtschaften"), where often only "external determinations" ("äußere Determinationen") caused separations and connections (LA I 9:202f).

14. Because of decisive experiences around 1806, Goethe reached a radical awareness of temporal and historical problems, which also manifested itself in his study of nature and art: the invasion of history and temporality into the study of nature led Goethe to an understanding of the history of science that is already articulated in the preface to the *Farbenlehre*: the "the history of science is science itself" ("Geschichte der Wissenschaft ist die Wissenschaft selbst"; [FA I 23.1:16]).[25]

15. This is a momentous insight. The current order of science is indebted to a history of its mediation by man and nature. The current order of science is also ephemeral. It is by its very nature transitory because the dynamics of science cannot be resolved by closure. Metaphysical attempts of ordering function in a certain metachronological fashion,[26] they want to go beyond time in a metachronological order. In the era of the *Wahlverwandtschaften*, Goethe was led toward the correlation of knowledge and time, as well as knowledge and history.

16. Goethe the naturalist and poet argued that it is necessary to reflect on the development of the order of science and scientific forms. The naturalist is confronted not only with the phenomena of nature but also with the history of research. Goethe uses a morphological approach to understand the dynamics of the history of science. At the same time, he wishes to establish

himself as a naturalist in a conscious relationship to the history of those fields of research in which he was personally involved. This is the claim of the historical part of the *Farbenlehre*. The naturalist also inherits the past. If he wishes to transform this into a conscious heritage and creatively unfold it further, then it is necessary to reflect upon the cultural genesis and mediation of this heritage. The naturalist must also be accountable for the manner in which tradition categorizes the objects of science and which cognitive and interpretive patterns it employs. In this manner the historical reference is constitutive for both natural science and anthropology. As Goethe simultaneously emphasized, it is the "history of man" that represents "man" (FA1 23.1:16).

17. The intervention of time and history into natural science makes it evident that scientific order at any given historical moment is provisional. Even the older Goethe remained firm in his conviction of the necessity of revisiting the orders of science with respect to the revisions of textbooks: "The expansion of knowledge requires a revision of the order of the sciences; it often happens according to new maxims, yet it always remains provisional" ("Bey Erweiterung des Wissens macht sich von Zeit zu Zeit eine Umordnung nöthig, sie geschieht meistens nach neueren Maximen, bleibt aber immer provisorisch"; [FA1 13:402]). The early essay "Der Versuch als Vermittler von Object und Subject" ("The experiment as mediator between object and subject"), an important work in the process of Goethe's self-understanding as a naturalist, had already warned of the inherent dangers of self-delusion in the attempt to finalize an object (WA2 11:33).

18. Soon after the publication of the *Wahlverwandtschaften,* it was Wilhelm von Humboldt who represented the ethos of a radically temporalized science. He defined its inherent modern infinitism as "something that has not yet been found and will never be found" ("etwas noch nicht ganz Gefundenes und nie ganz Aufzufindendes"). The organon of science, still

conceived as a principled idealistic development, could, according to Humboldt, only emerge creatively out of the "the depth of the spirit" and had to be looked for diligently ("unablässig . . . zu suchen"; [W. von Humboldt 253]).[27] In 1828 his brother Alexander spoke of the doubt that appeared to characterise the modern dynamics of science:

> Jeder Schritt, der den Naturforscher seinem Ziel zu nähern scheint, führt ihn an den Eingang neuer Labyrinthe. Die Masse der Zweifel wird nicht gemindert, sie verbreitet sich nur, wie ein beweglicher Nebelduft, über andere und andere Gebiete. Wer golden die Zeit nennt, wo Verschiedenheit der Ansichten, oder wie man sich wohl auszudrücken pflegt, der Zwist der Gelehrten, geschlichtet sein wird, hat von den Bedürfnissen der Wissenschaft, von ihrem rastlosen Fortschreiten ebenso wenig einen klaren Begriff als derjenige, welcher in träger Selbstzufriedenheit sich rühmt, in der Geognosie, Chemie oder Physiologie seit mehreren Jahrzehnten dieselben Meinungen zu vertheidigen. (A. von Humboldt 68)
>
> Every step the naturalist takes towards his goal leads to new labyrinths. The massive doubts will not decrease; like a fluid scent of fog they will spread to other areas. Whoever calls the era a Golden Era, where a variety of opinions, or, as one might also say, the dispute of the scholars, are settled, has no clear notion of the needs of science, of its incessant progress, as the one who boasts in lazy self contentment, that he has defended for decades the same opinions in geognosy, chemistry or physiology.

19. New modes of knowledge continually demand the transformation of systems of scientific knowledge. Around 1800 a significant paradigm shift[28] occurred in the field of chemistry: the old theory of chemical elective affinity as a result of Claude-Louis Berthollet's *Recherches sur les lois de l'affinité*, from 1801, and the *Essai de statique chimique*, from 1803, not only underwent a fundamental revision but were also ultimately waved aside as "simply for the history of the progress of the sciences" ("bloß zur Geschichte des Fortgangs der Wissenschaften; Karsten" 136). The chemist Berthollet had proven—against Torbern Bergman—that the processes of elective affinities showed no transparent "laws" of chemical reactions and could not be used for the precise prediction of experimental results. They were not based on constant properties of elements, which were independent of external events. And they did not possess a predetermined point of saturation.[29] Before Berthollet's work, the affinities that were responsible for chemical attraction were understood as "forces that were constant according to their specific character and had the capacity for saturation" ("substanzspezifisch konstante Kräfte mit Sättigungscharakter").[30] There is demonstrable evidence that Goethe knew of this "revolution"[31] in the chemistry of his period.[32] He allows the protagonists of the novel in the discourse on chemistry to refer back to an "antiquated" theory that had previously been understood as a foundation in the theoretical development of chemistry. He permits the protagonists in the novel to apply this same theory to their own lives in an inadequate manner. What did this mean?

20. The plot of the novel is not one that is structured after the model of the *attractio electiva duplex*. The novel narrates an interaction of open-ended relationships with a tragic outcome: four people suffer a wreckage of their lives. Such an outcome cannot be explained away using the method of Bergman's theory. The *separation* of a marital bonding is presented as something

that "appears indissoluble" ("unauflöslich schien"), but the cause of its own dissolution is present from the very beginning. The process of separation not only leads Charlotte away "into the open that has no boundaries" ("ins lose Weite"; [FA1 8:305]); the elective affinities of both Eduard and Ottilie and Charlotte and the Captain are also incapable of establishing themselves as new relationships. At the end of the novel, all the characters, even the minor ones, find themselves separated from one another as radically isolated individuals.[33] In what manner are the narrated plot line and the doctrines of the natural sciences linked with each other?

21. In the era of the *Wahlverwandtschaften*, the study of nature and the study of man are closely connected. Citing Alexander Pope from the pages of Ottilie's diary, it reads, "The study of Mankind is Man" ("das eigentliche Studium der Menschheit ist der Mensch"; [FA1 8:453]). Goethe tends toward a study of human nature as well as an investigation of the nature of the human and the natural basis of human life: the study of nature is a central paradigm of human self-knowledge.

22. In Goethe's anti-Cartesian turn, nature is an unavailable object of knowledge. The knowing subject of the study of nature is a part of the whole that is to be investigated. The subjectivity of the knowing subject cannot be annulled in a study of nature that is based on experience. In an epistemological sense, it always has to concern itself with the "mediation of object and subject."

23. In the era of the *Wahlverwandtschaften* and from the perspective of a philosophy of nature, Goethe teaches that between man and nature there is an absence of harmony. He cannot exclaim, as does Johann Wilhelm Ritter, "All of nature rhymes with man" ("Auf den Menschen reimt sich die ganze Natur"; [*Fragmente* 215]). He does not represent an anthropocentrism

in the study of nature; rather, like Kant, he is critical toward all forms of anthropomorphism. Nature is for him "Life and progress from an unknown centre to a boundary that cannot be known" ("Leben und Folge aus einem unbekannten Zentrum, zu einer nicht erkennbaren Grenze"; [LA1 9:295]).

24. On June 22, 1808, Goethe wrote to Zelter, "Man himself, as he uses his common sense" ("er Mensch an sich selbst, insofern er sich seiner gesunden Sinne bedient"), is "the greatest and most precise physical apparatus that exists" ("der größte und genaueste physikalische Apparat den es geben kann"; [FA2 6:329]). Exactly three days later, he developed a new structure for the novel. The cognitive-critical distance with regard to the exact sciences becomes even clearer. Goethe questions the limits of mechanical physics, and what necessarily escapes the discipline. The reduction of natural phenomena to their numerical value aroused his intense mistrust.[34] All scientific endeavours to "reinstate objectivity" elude recognition. The apparatus of physics does not appear as an extension but rather as a reduction of the means of knowledge on the side of the subject. Goethe pleaded against any separation of experimental science from the 'natural' experience of man. In a letter to Zelter, he declared:

> Und das ist eben das größte Unheil der neuern Physik daß man die Experimente gleichsam vom Menschen abgesondert hat, und bloß in dem was künstliche Instrumente zeigen die Natur erkennen, ja was sie leisten kann dadurch beschränken und beweisen will. Eben so ist es mit dem Berechnen. Es ist vieles wahr was sich nicht berechnen läßt, so wie sehr vieles, was sich nicht bis zum entschiedenen Experiment bringen läßt. *Dafür steht ja aber der Mensch so hoch, daß sich das sonst Undarstellbare in ihm darstellt.* Was ist denn eine

> Saite und alle mechanische Theilung derselben gegen das Ohr des Musikers? Ja, man kann sagen, was sind die elementaren Erscheinungen der Natur selbst gegen den Menschen, der sie alle erst bändigen und modifizieren muß, um sie sich einigermaßen assimilieren zu können? Doch in diese Betrachtungen will ich mich diesmal nicht verlieren; ich behalte mir vor nächstens besonders darüber zu reden, so wie noch über einige andre Punkte mir Auskunft zu erbitten. (FA1 6:329, emphasis added)
>
> And it is the greatest calamity of the new physics that it quasi separated experiments from the human being and only observes nature through artificial instruments; whatever nature achieved is thus limited and verified. It is the same with calculation. Much is true what cannot be calculated; and there is an equal amount that cannot be taken to the decisive experiment. *But it is man who is elevated to such a level that everything that otherwise can not be represented can be represented in him.* What is a string and every one of its mechanical partitions in comparison to the musician's ear? One can even ask, what are the fundamental phenomena in nature in comparison to man who has to tame and modify them in order to assimilate them? But I do not want to be lost in these thoughts; I will talk about them later and I will ask more questions about several other issues.

The "apprehensive *wunderkind*" (Härtl 100), Ottilie functions similarly in the novel; she is an exact physical apparatus in which the unrepresentable represents itself.

25. The pivotal idea of representation refers back to natural science as well as art. Goethe regarded nature as something that presents itself in the appearance of phenomena. The fundamental principle of morphology, almost certainly formulated in 1796, declared that "everything that is must also manifest and show itself" ("alles was sei sich auch andeuten und zeigen müsse"). According to Goethe, this principle was valid "from the first physical and chemical element to the mental human expression" ("von den ersten physischen und chemischen Elementen an, bis zur geistigsten Äußerung des Menschen"; [FA1 24:349]). These talks of the representation of the usually unrepresentable sounds like a programmatic phrase of romanticism, yet it alludes to an important change in Goethe's thinking. Beginning in the winter of 1805–06, Goethe—the "Protoromantiker," as Hans Blumenberg once called him (447)—had entered an intense debate with the younger generation of romantics. By constructing the category of representation of the unrepresentable, he had connected the problems of both natural science and literature in a complex interrelationship. It seems a bold narrative experiment that Goethe dedicates himself to narrate in a novel how the unrepresentable in nature can represent itself in man.

26. Montaigne proclaimed, "I do not educate, I narrate" ("Ich lehre nicht, ich erzähle"), when he described the narrative form of the *Essais*. The later Goethe quoted this line (MA18 2:517).[35] In the *Wahlverwandtschaften* a productive affiliation of the "knowledge" of the ancients with the knowledge of modern natural science and poetic narrative is mediated. The novel tells a story, builds up a narrative order and explores and constructs at the same time reality. In his *Wahlverwandtschaften*, Goethe takes up older, unrealised projects and alters them: he goes back to the 1787 proposal of "a novel about the universe" ("Roman über das Weltall")[36] and the experiments of a poetic natural doctrine; part

of this convolute is also his plan, articulated at the end of the 1790s, to write a lyrical poem on magnetism.[37] His project to narrate nature had changed when Goethe began to integrate cultural transformations of nature. Alexander von Humboldt is especially distinguished in the novel. "Only the naturalist should be honored" ("Nur der Naturforscher ist verehrungswert"), Ottilie's diary states, "who can describe and represent the foreign, strange, within its environment, its surroundings, its particular elements. How I would love to hear Humboldt talk about his experiences" ("der uns das Fremdeste, Seltsamste, mit seiner Lokalität, mit aller Nachbarschaft, jedesmal in dem eigensten Elemente zu schildern und darzustellen weiß. Wie gern möchte ich nur einmal Humboldten erzählen hören"; [FA1 8:452]).

27. The *Wahlverwandtschaften* belongs to a genre that integrated mesmerism into literature and transformed it into a romantic science, just as Goethe, Jean Paul, E. T. A. Hoffmann, and Heinrich von Kleist incorporated the phenomenon.[38] Elements of "animal magnetism," still current in the domain of magical observation of nature,[39] are woven into the narrative of *Wahlverwandtschaften* in such a detailed and subtle manner that only through several readings are all allusions revealed. As the narrator emphasizes, the "almost magic and indescribable attraction" ("unbeschreibliche, fast magische Anziehungskraft"; [FA1 8:516])[40] between Ottilie and Eduard is immediately evident. However, the somnambulism, which is of central significance for Ottilie's character, as well as the clairvoyance and sensitivity for minerals, are easily passed over in a reading although they are providing systemic connections. If one ignores for a moment that one of the main figures of the novel, the "arrival of a third person" (FA1 8:277), actually refers to the doctrine of chemical elective affinities,[41] one can say that the poetic transformation of the phenomena of animal magnetism is of considerably

more significance for the narrative plots and constellations of the *Wahlverwandtschaften* than any discourse on chemistry.

28. In the context of animal magnetism, current rationalizations as to why little Otto had Ottilie's eyes but resembled the Captain were offered and discussed. Goethe found in the *Jahrbücher der Medicin als Wissenschaft* from 1807 the theory that the imagination of the procreators can effect the very act of procreation and instantly convey shape and form to the fetus (Schelling, "Ideen" 15f).[42] It is the narrator who emphasizes the imagination of the procreators who are focused on their lovers in the night of the unprecedented event: "Eduard was embracing Ottilie; Charlotte imagined the major in close proximity" ("Eduard hielt nur Ottilien in seinen Armen; Charlotten schwebte der Hauptmann näher oder ferner vor der Seele"; [FA1 8:353]).

29. Familiar with the work through his conversations with Goethe in Karlsbad, Karl Friedrich von Reinhard emphasized after reading the novel that the questions of "relation" ("Verwandtschaft") and "affinity" ("Affinität") were based on the familiar doctrines of sympathy. Ottilie, apparently so close to nature, existed "in a continuous state of magnetization" ("in einem beständigen Zustand der Magnetisation"). Von Reinhard gave a quite accurate characterization of the liminality of the study of nature and its implied utopianism:

> Indessen wenn wir jemals zu einer tiefern Kenntnis der Geheimnisse *unsrer* Natur gelangen, so daß wir im Stande sind, uns davon Rechenschaft abzulegen, so ist es möglich, daß Ihr Buch alsdann als eine wunderbare Antizipation von Wahrheiten dastehe, von denen wir jetzt nur eine dunkle Ahndung haben. (Härtl 138, emphasis added)

> If we ever reach a more profound knowledge of the secrets in *our* inner nature so that we can be accountable, it will be possible to read your book as a wonderful anticipation of truths, which we can only sense at this moment in time.

30. What was so interesting for Goethe about animal magnetism in the era of the *Wahlverwandtschaften*? Even in 1851, Arthur Schopenhauer still refers to it in philosophical terms as "the most important of all discoveries" ("die inhaltsschwerste aller jemals gemachten Entdeckungen"). According to Schopenhauer, "a time will come when philosophy, animal magnetism and natural science, that has progressed in all directions, will be integrated in such a fashion that truths will appear which we never hoped to attain" („eine Zeit [wird] kommen, wo Philosophie, animalischer Magnetismus und die in allen ihren Zweigen beispiellos fortgeschrittene Naturwissenschaft gegenseitig ein so helles Licht aufeinander werfen, daß Wahrheiten zu Tage kommen werden, welche zu erreichen man außerdem nicht hoffen durfte"; [285]). The later Goethe, as is well known, distanced himself from the sensation ("Aufsehen") that mesmerism had precipitated throughout Europe around 1800; his personal reaction to it was "like one who walks along a river without any desire to swim in it" ("wie einer, der neben einem Flusse hergeht, ohne daß ihn die Lust zu baden ankäme"; [WA4 33:125]). In the era of the *Wahlverwandtschaften*, animal magnetism was not only a significant object of experimental research for the natural sciences at the university of Jena—in 1807, the philosopher Schelling also considered it to be a "a phenomenon that can no longer be neglected" ("nicht länger verkennbare Erscheinung"; ["Notiz" 493]).

31. The old doctrines of sympathy, which once belonged to the private religion of his youthful period (HA 9:350), Goethe studied anew[43] in the era of the *Wahlverwandtschaften*; with all

their hermetical and alchemical articulations, he integrated them into the issues debated in contemporary natural science. He thus fused the thoughts and cognitive forms of hermetical traditions and contemporary developments in science in the field of epic narration. Goethe, "the disguised hermetic" ("verkappte Hermetiker"), continued to be fascinated by the doctrine of sympathy, as the "life of nature," or, one may presume, he would not have made it the foundation of his narrative.

32. In 1808, Ritter had speculated on physiological experiments reaching into the magical-astral realms; the basic principle he called *Siderism*—an expanded version of Galvanism. In March 1808, Goethe had already studied Ritter's work *Der Siderismus oder Neue Beyträge zur nähern Kenntnis des Galvanismus*; he even took it with him to Karlsbad, where the first chapter of the *Wahlverwandtschaften* was dictated. The first part of Ritter's work—together with Lucretius's *De Rerum Natura*[44]—was included in his travelling chest of books. From April 5 through 9, 1808, he spoke with Thomas Seebeck about "siderism, divining rod, galvanism, mysticism" (*Siderismus, Wünschelruthe . . . Galvanismus, Mysticismus*; [WA3 3:327]). Many of the phenomena that Goethe incorporated in his novel are noted in a footnote in Ritter's work: for example, somnambulism (*Somnambulismus, Nachtwandeln*), clairvoyance (*Hellsehen*), sensitivity to light (*Hellfühlen*), hydrophobia (*Wasserscheu*), and effects of magnets (*Wirkung des Magnets*). Mentioned also is the effect of precious metals on neuropathy (*Siderismus* 10–13).[45] In another section, Ritter discusses vertigo and headaches during contact with metal as well as the discovery of coal, ore, and water springs with the divining rod.

33. The expectations of many naturalists around 1800 and their interest in phenomena such as Galvanism and Siderism were "the formation of concepts of physical forces as well

as chemical reactions and physiological sensations as connected by the same principles" ("sowohl physikalische Kraftvorstellungen als auch chemische Reaktionen und physiologische Abläufe als Ausprägungen eines Prinzipienzusammenhanges zu verstehen").[46] Goethe took a critical position toward the advancing disciplinary differentiation of the study of nature. He saw his *Farbenlehre* as a decisive step "to prepare through terminology and methodology a more complete unity of the knowledge of physics" ("durch Terminologie und Methode eine vollkommenere Einheit des physischen Wissens vorzubereiten"; [FA1 23.1:1043]). With some consternation, Goethe observed the differentiation, specialization, and partitioning of knowledge in the sciences through the formation of disciplines. In the context of his argument with galvanism, he believed that "in nature specific divisions are not possible" ("im Reiche der Natur keine besondern Reiche sich abstecken lassen").[47] When considering his physical discourses, lectures and experiments from the 1790s to 1806, one realizes that Goethe explored one basic underlying principle, which he saw exemplified in different phenomena of nature. It was duality, or polarity, (*Dualität*), the quest of the separated to be joined once again, sometimes at a higher (*gesteigert*) level, to bring forth a multiplicity, a "sparseness of nature" (*Sparsamkeit der Natur*) with considerably fewer basic principles (*Gundmaximen*).[48] In the era of the *Wahlverwandtschaften*, he prioritized unity in a nature that was diverse in itself.

34. With the poetic transformation of mesmerism, Goethe gained access to the discovery of the unconscious and anticipated romantic anthropology. He was also interested in the representation of phenomena that were inaccessible to human consciousness or volition. It was through the concept of somnambulism, which Goethe had studied intensively in Gotthilf Heinrich Schubert's *Ansichten von der Nachtseite der Naturwissenschaft* (13),[49] where

the notion of the *unconscious* in mesmerism and psychological research was developed. Mesmer's concept of hypnotism leads directly to the idea of psychotherapy.[50] Goethe's unique psychological and observational powers allow him to acknowledge phenomena such as narcissism and projection, to recognise them and appropriate them in a literary form. In the case of little Otto, the narrator has recourse to contemporary theories of somatic imagination and, in a somewhat breathtaking manner, manages to develop the psychodynamics of projection. Everyone sees in little Otto what they had previously projected onto him. The character of little Otto, a central element of the story, is simultaneously included in two different narrative forms. To this day, the reader has been puzzled by this. In the era of the *Wahlverwandtschaften*, the "continued work on physics" has the result that the "the anthropological phenomenon of the unconscious" is so thoroughly discussed in the novel, as "it has never happened in German literature before" (Matt 270).[51]

35. Goethe was not a closet mesmerist[52]; he was not a "wild" ("wildgewordener") Schellingian or a follower of Ritter. The poet maintained a healthy distance from the contemporary romantic study of nature, even when he took it seriously. As noted in his conversations with Hegel, he had "his fun" ("seine Späße")[53] by testing the swing of the pendulum that Ritter, together with Francesco Campetti, had undertaken and repeated in Goethe's presence. Traces are found in the passage of the novel where the pendulum is deployed by the Lord's companion, also a naturalist, who carries with him the hope that through more scrupulous experiments "certainly many a relation and affinity can be discovered between inorganic matter, organic matter that is opposed to inorganic matter, and, again, between organic and inorganic substances, which remain inaccessible to us at the moment" ("gewiß noch manche Bezüge und Verwandtschaften

unorganischer Wesen untereinander, organischer gegen sie und abermals untereinander, offenbaren würden, die uns gegenwärtig verborgen seien"; [FA1 8:480-81]). Not only is the English Lord sceptical; Charlotte also hesitates. The 1808 lyrical ballad *Wirkung in die Ferne* critiques a central element of the doctrine of sympathy, the *actio in distans* ("Kernelement der Sympathielehre, die actio in distans"; [Barkhoff, *Tag- und Nachtseiten* 87]), which is of some significance in the novel. It is through representation in art that Goethe can fictionalize "ways of imagining" (*Vorstellungsarten*) in the study of nature and that he can reflect upon this fictionalization and introduce to it social communicative processes and placement. It remains to be investigated how natural scientific models can be directly applied to social relations.

36. The question remains whether the novel as a whole is grounded in natural science. The verdict published in an anonymous review by Bernhard Rudolf Abeken, a private tutor to Schiller's children in Weimar from 1808 to 1810, certainly met with Goethe's approval. Goethe was so pleased with it that he had it printed separately and sent off to a number of his friends:

> Hier sehen wir, wie dieselben ewigen Gesetze, die in dem walten, was wir Natur nennen, auch über den Menschen ihre Herrschaft üben und ihm oft mit unwiderstehlicher Strenge gebieten; wie es eine, nur gesteigerte, Kraft ist, die leblose Stoffe zu einander zwingt und diesen Menschen zu einem andern zieht. . . . Die neuere Naturlehre wird noch manches Geheimniß in Bezug auf den Menschen enthüllen, vor dessen Offenbarung dem grauen möchte, welcher die Kräfte der Natur nicht als lebendige und ewige erkennt, und welchen die Beobachtung der Menschen und ihrer

> Schicksale nicht gelehrt hat, daß etwas in ihrem tiefsten Innern liegt, was über jenen Kräften ist, was vielleicht einer höhern Welt angehört. (Härtl 122, emphasis added)
>
> We notice how the same eternal laws that are innate in nature also dominate man and command his actions with a severity that he cannot resist; it is similar to the augmented force that coerces inanimate substances together and attracts humans to each other. . . . The new science will reveal many a secret in regards to man, which might be terrifying to those who do not recognize natural forces as alive and eternal; who have not learned from observing man and his fate that something is innate that is above those forces and belongs to another world.

By alluding to Goethe's own statement in the novel, Abeken points out that the narrative is emphasizing the natural origin of man yet does not limit him to this natural origin.

37. Through poetic transformation, natural science becomes an instrument for the investigation of both individual and social conflicts. If *elective* stands for freedom, and *affinities* for natural necessity, the title of the novel already indicates the core of the problem and posits a "critical paradox" ("brisantes Paradoxon"; [Schings 166]). The unrelenting attractions and repulsions between chemical elements in nature are compared with the violent to and fro of human passions, the "violence of passion" (FA1 8:505). Human passion is understood as a force of nature that exists beyond morality and can be investigated; it also becomes evident that human "freedom through reason" (*Vernunft-Freyheit*) is in the end ineffective (Härtl 51). The social

experiment represented in the novel raises the question to what extent man is able to recognize himself "in nature" (Härtl 51) and rediscover natural laws within himself. The natural foundation of human life is acknowledged, but at the same time, no undue "merging of spheres" (*sphärenvermengende*)[54] naturalization will take place. Goethe does not write in *Wahlverwandtschaften* of a humanisation of nature nor of a naturalisation of man. Yet there can be no doubt that through the medium of literature man's consciousness of freedom is clearly diminished.

38. In the era of the *Wahlverwandtschaften*, Goethe compares the different forms of rationality through morphology. The novel brings together imagery evoked from Greek myths, the emergence of the Christian cult of saints and ancient and contemporary forms of thought as well as modes of science and art. These various forms are of interest to the author while working on the novel since he understood them as symbolic disclosures and interpretations of the world. It is the narrator of the novel who perceives reality through the lenses of myth, religion, ethics, natural science, experimental science, and art, and who discovers what becomes visible in this manner. The novel investigates the different "processes of perception and interpretation of reality" ("Wahrnehmungs-[55] und Deutungsprozesse von Wirklichkeit"), and turns them into an artistic theme, which determines the poetic representation. The plot of the novel realizes what the protagonists and minor characters see and what they do not want to see, what kind of interpretation about life and reality they are engaged in. It is up to the reasoning power of the reader to discover the interrelationship between the narrative failure of the protagonists and their perceptions and interpretation of reality.

39. The study of both nature and art wants to disclose the connectedness of the real. Goethe was also concerned with the categories, patterns, forms, and practices of knowledge in their

relationship to a temporal and necessarily unavailable reality. He is not concerned about any "poetry of knowledge" ("Wissenspoetik");[56] he does not intend to use art to change the necessarily fragmentary quality of the empirical sciences into a complete whole. It is the reality of time and history[57] that also includes the transformation of the order of knowledge. Goethe understands this reality and also the social processes of change as a challenge to the achievements and orientations of art. The work of art does not simply rely upon a new didactic mediation of science but undertakes an all-embracing reflection of science within the framework of time and history. Since art distinguishes itself through self-reflectivity, self-reflection on scientific categories and modes of perception must also be promoted. Social knowledge is not woven into the novel for its own sake. It is integrated as a representation of a specific experience and appropriation of the world—namely, within the framework of an artistic morphology of the relations of reality. The poetics of the novel is not aimed at science; rather, it is aimed at the disclosure of the real.

40. Looking back at the reception of his work, Goethe stated, "no one wanted to admit that science and poetry could be integrated. It was forgotten that science evolved out of poetry; it was not anticipated that after times have changed, both could again on a higher level encounter each other in a friendly and mutually beneficial way" ("nirgends wollte man zugeben, daß Wissenschaft und Poesie vereinbar seien. Man vergaß daß Wissenschaft sich aus Poesie entwickelt habe, man bedachte nicht daß, nach einem Umschwung von Zeiten, beide sich wieder freundlich, zu beiderseitigem Vorteil, auf höherer Stelle, gar wohl wieder begegnen könnten"; [LA1 9:67]). Nevertheless, around 1800, Goethe could have found many people of the same mind (*Gleichgesinnte*), who believed in a closer cooperation of science and art. In the era of the *Wahlverwandtschaften*, Goethe

saw the conjunction of science and art as an innovative form of social rationality. In the *Geschichte der Farbenlehre*, which he wrote simultaneously with the *Wahlverwandtschaften*, he developed the "comparison of art and science" ("Vergleichung der Kunst und Wissenschaft") as follows:

> Da im Wissen sowohl als in der Reflexion kein Ganzes zusammengebracht werden kann, weil jenem das Innre, dieser das Äußere fehlt; so müssen wir uns die Wissenschaft notwendig als Kunst denken, wenn wir von ihr irgend eine Art von Ganzheit erwarten. Und zwar haben wir diese nicht im Allgemeinen, im Überschwänglichen zu suchen, sondern wie die Kunst sich immer ganz in jedem einzelnen Kunstwerk darstellt, so sollte die Wissenschaft sich auch jedesmal ganz in jedem einzelnen Behandelten erweisen.
>
> Um aber einer solchen Forderung sich zu nähern, so müßte man keine der menschlichen Kräfte bei wissenschaftlicher Tätigkeit ausschließen. Die Abgründe der Ahndung, ein sicheres Anschauen der Gegenwart, mathematische Tiefe, physische Genauigkeit, Höhe der Vernunft, Schärfe des Verstandes, bewegliche sehnsuchtsvolle Phantasie, liebevolle Freude am Sinnlichen, nichts kann entbehrt werden zum lebhaften fruchtbaren Ergreifen des Augenblicks, wodurch ganz allein ein Kunstwerk, von welchem Gehalt es auch sei, entstehen kann. (FA1 23.1:605)
>
> Knowledge and reflection cannot create a whole because the former lacks the internal and the latter the external qualities. We therefore have to imag-

ine science as art if we expect any kind of unity. But we cannot look for it in the general, in the extraordinary, but in the representation of art in the individual work of art. With science it is the same; it will prove itself as a whole in the individual experiment.

To approach this kind of challenge we cannot exclude any of the human actions in the scientific endeavor. The abyss of the avengement, a certain perception of the present, mathematical depth, physical precision, reason, understanding, resourceful and fluid imagination, loving enjoyment of the passions—nothing can be excluded in the vivid and procreative grasp of the moment, in which the work of art alone—whatever its content—can be created.

NOTES

1. In traversing a spiral motion, the complexity of the object is exposed incrementally.

2. See Goethe's self-advertisement of the novel in "Morgenblatt für gebildete Stände" (Tübingen, 4. September 1809), in Härtl 51.

3. In this essay, the five Goethe sources cited have two-letter abbreviations. See the Goethe entries in the bibliography for clarification. See HA 1:306: "'Magnetes Geheimnis, erkläre mir das!' Kein größer Geheimnis als Lieb' und Haß." ("'The secret of the magnet, explain that to me!' There is no greater secret than love and hate.) See also LA1 6:362.

4. With this title, the Munich edition, which arranges Goethe's writings according to epochs, titles the years 1807–14. Cf. MA 9.

5. The concept of the *Urphänomen* is developed in the context of the work in the *Farbenlehre*. See §§ 174ff in FA1 23.1:80ff.

6. See also Goethe, *Physikalische Vorlesungen* (1808) in MA 9:919ff; see also the commentary MA 9:1404f.

7. See Zabka, *Pragmatik der Literaturinterpretation.*

8. Goethe, in Härtl 51.

9. See Adler 165f.

10. Christoph Martin Wieland to Elisabeth Gräfin von Solms-Laubach, June 15, 1810.

11. See Karl Wilhelm Ferdinand Solger, "Über die 'Wahlverwandtschaften,'" 1809–10, in Härtl 201.

12. See Blechschmidt, " . . . Eine Repositur."

13. See Goethe an Karl Friedrich von Reinhard, February 21, 1810, in Härtl 139. The accompanying documents of the "Geschichte der Farbenlehre" were described as the "zweyter Theil des Farbenwesens."

14. See Karl Wilhelm Ferdinand Solger to Bernhard Rudolf Abeken, 28. Oktober 1810, quoted in Härtl 172: "Die *Farbenlehre* hat mich auch gewissermaßen überrascht. . . . Nun ist es ein Buch, worin die Natur lebendig, menschlich und umgänglich geworden ist. Mich dünkt, es giebt auch den *Wahlverwandtschaften* einiges Licht" (I was also surprised by the *Farbenlehre*. . . . It is a book in which nature is alive, human and accessible. I believe that it also sheds light on the *Wahlverwandtschaften*). See also Schaeder, *Gott und Welt,* 276ff.

15. See Letter to Schiller, August 17, 1797. WA4 12:247.

16. See Hühn, "Wissenschaft II."

17. See also § 720, FA1 23.1:233.

18. See Helbig 19f.

19. On Goethe's procedural methods see also "morphologischen Methode" by Goethe und Wittgenstein in Schulte 11–42.

20. Ludwig Wittgenstein develops a method and form of presentation of the *perspicuous presentation* with recourse to Goethe's morphology, in his remarks on Frazer's *The Golden Bough* in Wittgenstein, "Bemerkungen," esp. 37.

21. See also Hühn, "Der rote Faden."

22. On Goethe's ambivalent relation to romantic natural science, see von Engelhardt.

23. For a perspective on the novel, see also Mittermüller, 59ff.

24. See Notat von Friedrich Wilhelm Riemer, October 21, 1805, in Herwig 2173.

25. Cf. Blechschmidt, *Goethes lebendiges Archiv*, and Thadden.

26. See Theunissen.

27. See also Hühn, "Wissenschaft II" 918f.

28. See Kuhn.

29. See Fischer 510: "Wenn auf einen Stoff A, zu gleicher Zeit zwei andere Stoffe, B und C, wirken, welche Verwandtschaftskräfte gegen A haben, so wählt A nicht einen von beiden, wie die bisherige Theorie will, sondern theilt sich in jedem Fall zwischen beiden. Aber das Verhältniß in welchem A sich theilt, ist von so vielerley Umständen abhängig, daß es, wenigstens bei dem gegenwärtigen Zustand der Theorie so gut als unmöglich ist, dasselbe in jedem Fall durch bestimmte Zahlen a priori zu bestimmen." ("If two substances, B and C, which have an affinity to substance A, react to that substance, then A does not choose one of the two, as the theory up to now stated, but divides itself between the two. But the relation into which A divides itself depends on so many circumstances, that it is impossible, at least at this moment in time, to define it *a priori* in each case with certainty.")

30. See Carrier 379.

31. According to Fischer 503f.

32. See Goethe to Count Kaspar von Sternberg, September 19, 1826, in WA4 41:169; and Hoffmann, esp. 427f.

33. See Osterkamp.

34. See also Cassirer 57.

35. See Thadden 49 ff.

36. See Schaeder.

37. See Goethe to Knebel, Juli 16, 1798, in WA4 13:213: "Ich denke vielleicht ehestens ein Gedicht über die magnetischen Kräfte, auf eben die Weise, aufzustellen. Man muß einzeln versuchen was im Ganzen unmöglich werden möchte." ("I am planning to write a poem on magnetic forces in the same way. One has to separate what is impossible to compose as a whole.")

38. See Jürgen Barkhoff, *Magnetische Fiktionen*, and his "Tag- und Nachtseiten."

39. See Florey 20, 25.

40. For a discussion of the phenomenon of magnetic animal love, see also Ritter, *Fragmente* 84f.

41. In the foreword to Scheffer's *Chemische Vorlesungen*, Torbern Bergman defined *elective affinity* such that two substances that are united with each oth-

er separate and unite with a third substance that enters into their relationship ("zwei Stoffe mit einander vereinigt sind, und ein dritter, der hinzukommt, einen derselben aus seiner Verbindung trennt und ihn zu sich nimmt"). Scheffer xvii.

42. See also Hufeland 118; cf. the fundamental work of Holtermann 182.

43. Cf. the diary entry for March 25, 1809, in WA3 4:18, with reference to Pico della Mirandola, Agrippa von Nettesheim and "Cabbalistische Lehrer"; on Goethe's doctrines on sympathy, see also Breidbach.

44. See WA3 3:420; on the significance of the work for Goethe, see also the letter to Friedrich Heinrich Jacobi, March 31, 1808, in WA4 20:38f.

45. See also Holtermann 178.

46. See Breidbach and Ziche 11; cf. Herder, *Adrastea* 5:10. FA 10:829: "Und im Reich der Kräfte, haben der Magnet, die Elektrizität, der Galvanismus keine neuen Ansichten der Dinge verliehn? Haben Linné, Haller, Werner den Dingen der Welt keine neue Ordnung gegeben?" ("And in the realm of forces, have not the magnet, electricity and galvanism opened up new perspectives of things? Have not Linné, Haller, and Werner provided a new order of things?")

47. See Galvanismus, in WA2 11:200, with recourse to the transgressing the realms ("Reiche") of physics and chemistry.

48. See *Physikalische Vorträge schematisiert* (1805–06), in MA 6.2:834ff.

49. Cf. Adler 192–202.

50. See also Schott.

51. See Beland.

52. Goethe knew that Mesmer had treated his patients with a "magnetischen Fluidum"; cf. *Physikalische Vorträge schematisiert* (1805–06), in MA 6.2:868: "Frühere Annäherung des Eisenmagnetismus zu menschlichen Kuren. Mesmerische Wannen." On the complementary medicine of mesmerism, Goethe retained a characteristic critical distance. Traces of this are also found in the novel; see *Die Wahlverwandtschaften* II:11, in FA1 8:481f.

53. See the letter Hegel to Schelling, February 23, 1807, in *Johann Wolfgang von Goethe: Begegnungen und Gespräche*, vol. 6: 1806–08, Renate Grumach, ed. (Berlin: de Gruyter 1999), 217; cf. Adler 180–87.

54. See Pörksen.

55. See also Hühn, "Die 'Wahlverwandtschaften'" 26.

56. See the contributions in Brandstetter.

57. A time in which as the novel emphasizes "[sich] über die Menschen"

as well as "über die Denkmäler . . . ihr Recht nicht nehmen [lässt]." ("that does not give up the right over humans . . . and monuments.") *Die Wahlverwandtschaften* II:2, in FA1 8:404.

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The Collision between Physics and Metaphysics in England around 1800

Kathleen Lundeen

For centuries the assumption that the universe is constituted of differentiated and undifferentiated space so pervaded Western thinking, it was taken by most as axiomatic. Though at the core of this assumption is a paradox—the coexistence of the definite and the indefinite—accepting the paradox served a variety of interests: it allowed scientists to account for immeasurable space in a contained universe; it enabled theologians to argue that an unbounded soul exists in a mortal body; it legitimized imperialists' geopolitical containment of their endless expansion; and it had semiotic value since the blank space of a page, assumed to be free of signification, provided a backdrop against which words (or images) could be distinguished from one another and acquire meaning. In the late 1700s the differentiated/undifferentiated paradigm encountered two serious challenges. Joseph Priestley, the ambidextrous English thinker who worked in the arenas of philosophy, theology, and science, refuted the logic of the paradigm while William Herschel, England's foremost astronomer of the period, destabilized the paradigm through both rational argument and empirical discoveries.[1]

In the period swirling around 1800, English literary writers entered the fray—in some cases directly, in other cases tangentially—and wrestled with the differentiated/undifferentiated paradigm. The result of this collective philosophical, scientific, and literary effort was a reconceptualization of space. In the following discussion I will briefly present the justification of the differentiated/undifferentiated paradigm in the late seventeenth century by the preeminent scientist and the preeminent philosopher of the period, and I will follow with Priestley's and Herschel's rebuttals, which came nearly a century later. I will then show how several English poets wriggled out of the paradigm in the early nineteenth century, which enabled them to imagine the universe as it would be seen by twentieth-century physicists. The correlation between English romantic poetry and twentieth-century physics has been convincingly established in other critical studies. In this analysis I will extend the dialogue by revealing how liberation from the differentiated/undifferentiated paradigm was essential to the poets' ability to unchain themselves from the Newtonian universe.[2]

In 1687 Isaac Newton confirmed in his *Principia* the longstanding view that the universe consisted of differentiated and undifferentiated space, tangible substance and vacuums:

> All spaces are not equally full. For if all spaces were equally full, the specific gravity of the fluid with which the region of the air would be filled, because of the extreme density of its matter, would not be less than the specific gravity of quicksilver or of gold or of any other body with the greatest density, and therefore neither gold nor any other body could descend in air. For bodies do not ever descend in fluids unless they have a greater specific gravity. . . . If all the solid

> particles of all bodies have the same density and cannot be rarefied without pores, there must be a vacuum. (810)

A few years later John Locke made a similar claim in his *Essay Concerning Human Understanding*: without vacuums, he argued, there would be no place for matter to relocate. He acknowledges that "the difficulty is, how we come by those *boundless ideas* of eternity and immensity; since the objects we converse with come so much short of any approach or proportion to that largeness," but he surmises that, since our reasoning is constricted by the framework of our experience, infinity can only be conceived as the extension of finiteness (277–78). Since the infinite is not taken to be the antithesis of the finite but its expansion, such a view of infinity proves to be useful in resolving the paradox of the infinite coexisting with the finite.

Newton's and Locke's reasoning held steady for nearly a century, but in the latter part of the eighteenth century, Joseph Priestley confronted the differentiated/undifferentiated paradigm head-on. In his *Disquisitions Relating to Matter and Spirit*, he declares, "man does not consist of two principles so essentially different from one another as *matter* and *spirit*, which are always described as having no one *common property*, by means of which they can affect, or act upon, each other . . ." (xiii). In the same discussion he elaborates, stating, "[The] notion of two substances that have no *common property*, and yet are capable of *intimate connection* and *mutual action* is both absurd and *modern* . . ." (xxxviii). Though Priestley acknowledges, "It has been asserted . . . that . . . all the solid matter in the solar system might be contained within a nut-shell, there is so great a proportion of *void space* within the substance of the most solid bodies" (17), he disposes of that assertion by arguing, "*matter is infinitely divisible* . . ." (72). He further proposes in his sequel (which is appended to the *Disquisitions*) that "what we call *mind*, or the principle of perception and thought, is not a substance distinct from the body, but the result of corporeal organization . . ." (355). Priestley's solution to the paradox of the definite coexisting with the indefinite or, more specifically, matter coexisting with mind is to argue there is no duality; all is matter. What we refer to as mind or soul or spirit, he implies, is just another form of matter.

Almost contemporaneous with Priestley's *Disquisitions* is a paper by William Herschel in which he also rejects the mind-matter duality. In his 1780 paper "On the Existence of Space" he offers a rational rather than empirical argument regarding the nature of space, defining it as "a simple, infinitely-extended Existence" (1:lxxxvi):

> It is to me the most inconceivable thing, that the very name of Space does not convey to every one who hears, and understands the meaning of it, the Idea of something really existing. Inane, vacuum, plenum, room, place, distance; call it what you please; How could we exist but in space? How could I stretch out my hand if there was no room! Could we get up and walk if we did not leave the place we were in! If we go sometime straight forward are we not at a distance from the place we set out? How idle it would be for philosophers to talk of a plenum or vacuum if neither of these terms meant anything really existing. (1:lxxxvii)

Herschel resolves the problem of the coexistence of the definite and the indefinite, which he specifies as "space" and "vacuums," through a maneuver similar to Priestley's: he rejects the duality and argues that what we term *vacuums* or *voids* are, in truth, other forms of space.

Though the achievement for which Herschel is most remembered is his discovery of Uranus in 1781, his far more dramatic contribution to astronomy is his reconceptualization of the nature of space. In a 1785 paper, Herschel offers empirical evidence to support the philosophical argument in his 1780 paper, and his report includes a startling observation: with the aid of a telescope, an observer discovers that "the milky way . . . [and] those objects which had been called nebulae are evidently nothing but clusters of stars" (1:226). Further, he "finds their number increase upon him, and when he resolves one nebula into stars he discovers ten new ones which he cannot resolve" (1:226). In another paper he extrapolates from his observations that the entire cosmos is in a perpetual state of dissolution and reconstitution. In particular, he notes, our own galaxy is gradually dissolving: "it is evident that the milky way must be finally broken up, and cease to be a stratum of scattered stars" (2:540). He concludes his discussion with what he argues is the inevitable fate of our galaxy: "the breaking up of the parts of the milky way affords a proof that it cannot last for ever [and] it equally bears witness that its past duration cannot be admitted to be infinite" (2:541). In short, Herschel erases the picture of the universe as amorphous, immutable space, punctuated with defined stars, and replaces it with a view of a dynamic and mutable cosmos throughout which stellar phenomena are diffused.

Thanks in large part to Herschel, who oversaw the construction of several hundred telescopes and sold them to professional and amateur astronomers in England and on the continent, by the end of the eighteenth century, astronomy had become a public enterprise. Herschel's new view of the universe did not, therefore, remain in a hermetic circle of professional scientists, and it did not escape the notice of romantic writers, several of whom responded to what they saw as the obsolescence of the longstanding paradigm of differentiated and undifferentiated space. In the balance of this essay I will observe how several poets break free of the paradigm and become unwitting prophets of twentieth-century physics.

Samuel Taylor Coleridge addresses the paradox of the coexistence of the definite and the indefinite primarily through philosophy and theology. His tendency to see physics subsumed by metaphysics was a predisposition from a young age. When he viewed the night sky as a boy, he claims, he was underwhelmed by the experience since the breathtaking possibility of immeasurable space had already been awakened in him:

> I remember, that at eight years old I walked with [my father] one winter evening from a farmer's house, a mile from Ottery—& he told me the names of the stars—and how Jupiter was a thousand times larger than our world—and that the other twinkling stars were Suns that had worlds rolling round them—& when I came home, he shewed me how they rolled round. . . . I heard him with a profound delight & admiration; but without the least mixture of wonder or incredulity. For from my early reading of Faery Tales, & Genii &c &c—my mind had been habituated *to the Vast*—& and I never regarded *my senses* in any way as the criteria of my belief. I regulated all my creeds by my conceptions not by my *sight*—even at that age. (*Collected Letters* 1:354)

As a teenager, Coleridge spent hours alone, stargazing on a flat roof at his school, and when he lived at Greta Hall some fifteen years later and acquired a telescope, he resumed his nightly gazing. In spite of his sustained interest in astronomy, the telescope appears in his writing as a metaphor. In 1800 he wrote a short poem "Apologia Pro Vita Sua," for example, in which he portrays the imagination as transforming the poet's eyes into a telescope through which he can perceive an infinite realm:

> The poet in his lone yet genial hour
> Gives to his eyes a magnifying power:
> Or rather he emancipates his eyes
> From the black shapeless accidents of size—
> In unctuous cones of kindling coal,
> Or smoke upwreathing from the pipe's trim bole,
> His gifted ken can see
> Phantoms of sublimity. (1–8)

A few years later in a notebook entry he is even more direct in using the telescope to describe a sublime faculty of perception: "a great metaphysician . . . looked at his own Soul with a Telescope / what seemed all irregular, he saw & shewed to be beautiful Constellations & he added to the Consciousness hidden worlds within worlds" (*Notebooks* 1:1798). Since Coleridge first experienced "the Vast" through his imagination, we might conclude that the most sophisticated telescope could not compete in giving him access to the infinite.

When Coleridge muses over the differentiated/undifferentiated paradigm, he finds it to be fraught with logical and logistical problems:

> what is Space, but the universal antecedent Form and ground of all Seeing? Now that *Space* belongs to the mind itself, i.e. that it is but a *way* of contemplating objects, you may easily convince yourself by trying to imagine an outward space. You will immediately find that you imagine a space for *that* Space to exist in—in other words, that you turn this first space into a *thing* in space. . . . (*Collected Letters* 6:630)

These comments appear in a letter, and their slightly dizzying effect arises from the deconstruction of the term *space*, which can refer to occupied area or unoccupied area. To paraphrase Coleridge, we imagine an unoccupied area (empty space) for an occupied area (filled space) to dwell in, but that leaves us with the question, what does the empty space consist of? In his wrestling with the ontology of the two kinds of space (empty and filled), Coleridge rejects the path of least resistance—namely, that empty space is a vacuum.

In his *Biographia Literaria,* Coleridge considers the problem of the longstanding spatial paradigm at the quantum level: "Matter has no *Inward.* We remove one surface, but to meet with another. We can but divide a particle into particles; and each atom comprehends in itself the properties of the material universe" (133). This musing of Coleridge's is particularly illuminating. If, as Coleridge reasons, the attempt to discover an irreducible material element is continually deferred, then, we might infer, matter at its most rudimental is *idea* rather than *thing.* To Coleridge, the elusive nature of matter, whose origin cannot be determined, locates physics in the realm of metaphysics, as I will show momentarily. Coleridge's argument that the search for the irreducible core of matter is futile, yielding an unending deferral, is consistent with his wrestling over the nature of space. Just as matter has no inward, it also, he implies, has no outward. What one imagines to be the utmost interior of an atom or the utmost exterior of space—that is, inner emptiness or outer vacuity—is yet another layer of reducible material substance.

Coleridge's resolution to the conundrums regarding the nature of the atom and the cosmos is metaphysical, and it enables him to circumvent the logical and empirical dilemmas caused by the apparent coexistence of differentiated and undifferentiated space. He declares space to be "a form of all perception" (a status he also gives to time [*Notebooks* 3:3973]), "a mode of Seeing" (*Notebooks* 4:4522). He does not stop there, however, but reasons syllogistically that since "we see all things in God" and "we cannot perceive except under the form of Space & Time," God equals space and time (*Notebooks* 3:3974).

Coleridge's equating God with time and space is not a passing thought. He often conflates theology and physics, and, as a result, his religious reflections are frequently scientific reflections. His poem "Religious Musings," which was written in the 1790s, is worth considering in this discussion since he refutes the differentiated/undifferentiated paradigm by closing the gap between the Creator and his creation:

> From Hope and firmer Faith to perfect Love
> Attracted and absorbed: and centered there
> God only to behold, and know, and feel,
> Till by exclusive consciousness of God
> All self-annihilated it shall make
> God its identity: God all in all!
> We and our Father one! (39–45)

He pursues this idea of all-encompassing oneness later in the poem, declaring, "There is one Mind, one omnipresent Mind, / Omnific . . . [whose] most holy name is Love" (105–06), and presents a view of human and divine ontology:

> 'Tis the sublime of man,
> Our noontide majesty, to know ourselves
> Parts and proportions of one wondrous whole!
> This fraternises man, this constitutes
> Our charities and bearings. But 'tis God
> Diffused through all, that doth make all one whole . . .
> (126–31)

His communitarian vision depends on God being "Diffused through all," which dissolves the binary of differentiated and undifferentiated space. The alternative, Coleridge argues, is humanity living as "An anarchy of Spirits," with "No common centre"; in such a state, he contends, man exists as "A sordid solitary thing, / Mid countless brethren with a lonely heart / Through courts and cities the smooth savage roams / Feeling himself, his own low self the whole" (146–52). Coleridge completes his thought by describing the freedom that would accompany man if instead he were "diffused" (Coleridge repeats the key term) with divinity:

> . . . he by sacred sympathy might make
> The whole one self! Self, that no alien knows!
> Self, far diffused as Fancy's wing can travel!
> Self, spreading still! Oblivious of its own,
> Yet all of all possessing! This is Faith!
> This the Messiah's destined victory! (153–58)

In this compressed statement of salvation, Coleridge proposes, man would simultaneously spread himself and possess all, the undifferentiated and differentiated capabilities functioning in a complementary fashion. Though it might appear that the poem presents reconciliation between the differentiated and undifferentiated, matter and mind, Coleridge declares the priority of the "one Mind," "diffused" through all and of which all is a part.

In 1801, several years after writing "Religious Musings," Coleridge claimed in a letter to have "completely extricated the notions of Time, and Space . . ." (*Collected Letters* 2:706). The following year he wrote a hymn that could have been titled "Scientific Musings." In the poem ("Hymn Before Sun-Rise in the Vale of Chamouni") his intimations of relativity are roused by the sublimity of Mont Blanc. The apostrophe to the mountain that begins the poem suggests the mountain has transcended temporal and spatial parameters: "Hast thou a charm to stay the morning-star / In his steep course? So long he seems to pause / On thy bald awful head, O Sovran Blanc" (1–3). Just as time has been arrested by the mountain, space seems unconfined:

> . . . Around thee and above
> Deep is the air and dark, substantial, black,
> An ebon mass: methinks thou piercest it,
> As with a wedge! But when I look again,
> It is thine own calm home, thy crystal shrine,
> Thy habitation from eternity! (7–12)

Later in the poem the suggestion recurs that in the realm of the mountain there has been a suspension of temporal and spatial restrictions: "Torrents, methinks, that heard a mighty voice, / And stopped at once amid their maddest plunge! / Motionless torrents! silent cataracts!" (51–53).

The refusal in the poem to allow reconciliation between matter and mind, a convergence of the differentiated and the undifferentiated, is incisive. Coleridge writes at the end of the first stanza:

> O dread and silent Mount! I gazed upon thee,
> Till thou, still present to the bodily sense,
> Didst vanish from my thought: entranced in prayer
> I worshipped the Invisible alone. (13–16)

Though he draws a clear distinction between "the bodily sense" and his "thought," which do not coalesce, he notes a few lines later that the mountain "wast blending with my thought" (19). Mont Blanc ceases to be perceived as a physical phenomenon in the poem but is received as a metaphysical phenomenon, a "kingly Spirit throned among the hills," as Coleridge proclaims toward the end of the poem (81). Many critics, including Mark Lussier, have shown that English romantic poets resist the matter-mind duality (*Romantic Dynamics* 96). The deconstruction of the duality in their poetry does not, however, cause a blending of matter and mind but rather a gesture toward the supremacy of mind. In a discussion of Coleridge's forays into several of the natural sciences, Eric Wilson remarks that the poet hoped through science to reconcile the poles of "proto-ecological vision and Platonic hope for transcendence[,] . . . thus marrying spirit and matter, mind and body" (641). As Wilson observes, however, Coleridge, influenced by Kant and the German idealists, "pulled away from the concept of an embodied mind" (647). Wilson goes on to note that "he became increasingly convinced that the mind is a transcendental power, a faculty not dependent upon physical organization" (647). This recognition, I argue, was critical to Coleridge's ability to wrest himself from the concept of absolute time and space.

Though around 1800 several English poets had inklings of Einstein's general theory of relativity, John Keats, like Coleridge, expressed directly his disregard for viewing time and space as fixed parameters. In the summer of 1818, while hiking in Scotland with a friend, Keats wrote a letter in journal style to his brother Tom. The second entry begins: "June 26—I merely put *pro forma*, for there is no such thing as time and space . . ." (*Letters* 1:298). After disavowing the existence of time and space, he indicates that the realization "came forcibly upon me on seeing for the first hour the Lake and Mountains of Winander . . ." (298). In the description that follows, his resistance to the differentiated/undifferentiated paradigm is expressed through poetic sensibility rather than philosophical argument. The natural scene, he writes, consisted of "beautiful water—shores and islands green to the marge—mountains all round up to the clouds" (298). Though Keats attributes the beauty of the natural universe to his liberation from the restrictions of time and space, Herschel may also have had a hand in that liberation. Keats did not own a telescope, but his enthusiasm for astronomy, and in particular for Herschel, is reflected in his sonnet "On First Looking into Chapman's Homer." In an allusion to the astronomer's discovery of Uranus, he writes that upon reading a new translation of Homer, he felt "like some watcher of the skies / When a new planet swims into his ken" (9–10).

Two years after renouncing time and space, Keats, in a letter to Percy Shelley, further reveals his proclivity for seeing the universe as replete, without any empty areas. In a paraphrase of a line from *The Faerie Queene*, he advises his fellow poet to "'load every rift' of your subject with ore" (*Letters* 2:323). A year earlier he took that approach in his ode "To Autumn," a luminous instance of transcending absolute time and space by surmounting the differentiated/undifferentiated paradigm.[3] Throughout his letters and poetry, Keats reveals both his discomfort with empty spaces and his sense that time and space are malleable hypotheses rather than intractable conditions of the physical universe.

In one of his final poems, "This living hand, now warm and capable," Keats takes a brash approach and openly flaunts his disregard for temporal and spatial constraints. The poem in its entirety reads:

> This living hand, now warm and capable
> Of earnest grasping, would, if it were cold
> And in the icy silence of the tomb,
> So haunt thy days and chill thy dreaming nights
> That thou would wish thine own heart dry of blood,
> So in my veins red life might stream again,
> And thou be conscience-calm'd. See, here it is—
> I hold it towards you. (1–8)

At the start of the poem, the speaker asserts the mortal state of his hand through a familiar adverb of temporality: his hand is living "now" and thus has spatial as well as temporal presence, but, we gather, "now" will one day give way to "then" and the hand will be dead. He undercuts that temporality, however, by treating death as a hypothesis rather than a certainty. His hand, he states, "*would*" haunt the one to whom he is speaking "if it were cold / And in the icy silence of the tomb," and the person to whom the poem is addressed "*would*" wish to surrender her own life so he could live (my emphasis). Without warning, the speaker abruptly halts his hypothesis with an apostrophe: "See, here it is— / I hold it towards you." Just as he breaks out of the two-dimensional space of the page by thrusting his hand toward the reader, he breaks out of the linear sense of time through the spatial adverb. The hand is here in the present moment, indicated at the start of the poem, and is already here in the future moment, established by the hypothesis. Keats's "living hand" involves a sleight of hand. Through rhetorical trickery, including the subjunctive mood and the surprise apostrophe, Keats circumvents temporal and spatial restrictions and by doing so exposes time and space to be rhetorical gestures rather than physical constants. As noted above, his resistance to the differentiated/undifferentiated paradigm, expressed in both his letters and poetry, liberates him from the Newtonian universe and its accompanying strictures of absolute time and space.

Six years before Keats advises Shelley to load ores into rifts, Shelley wrestles with the differentiated/undifferentiated paradigm in his essay "A Refutation of Deism," where he asserts: "That which is infinite necessarily includes that which is finite. The distinction therefore between the Universe, and that by which the Universe is upheld, is manifestly erroneous." He concludes that "the words God and Universe are synonymous" (56). If one assumes he uses the terms *infinite* and *finite* to represent *God* and *Universe*, then his reasoning is underdeveloped:

if the infinite (God) includes the finite (the universe), the two terms are not synonymous since that which does the including is greater than that which it includes. One way around the logical inconsistency, however, is to argue that if God and the universe are the same, then either what appears to be infinite is actually finite or, conversely, what appears to be finite is in fact infinite. In his later essay "On Life," Shelley gives priority to infinity:

> [There] is a spirit within [man] at enmity with nothingness and dissolution (change and extinction). This is the character of all life and being.—Each is at once the centre and the circumference; the point to which all things are referred, and the line in which all things are contained.—Such contemplations as these[,] materialism and the popular philosophy of mind and matter, alike forbid; they are consistent only with the intellectual system. (476)

Shelley may owe his metaphysical development in part to Keats, whose advice to Shelley, quoted earlier, was written in a letter in 1819, but Mary Godwin may also deserve some credit for the refinement of his thought. In 1816 she gave him a telescope, and, in his "Essay on Christianity," written within a year of receiving the instrument, he writes, "Man was once as a wild beast . . . [but] has become a moralist a metaphysician a poet and an astronomer . . ." (250). With the aid of a telescope, Shelley, like Herschel, saw a dynamic cosmos, but unlike Herschel he rejected dissolution as a principle of "life and being."

In his towering poem "Mont Blanc," Shelley describes the difficulty of coming to terms with the ontology of the mountain: is it a physical or metaphysical phenomenon? The deft maneuvers through which he attempts to answer that question provide an uncanny illustration of the uncertainty principle. Arkady

Plotnitsky has referred to "Mont Blanc" as "an especially fitting counterpart of Heisenberg's vision" and has described the poem as an allegory that moves from a "classical view of the world" to a "quantum-mechanical, Heisenbergian, sense of the world" (34).[4] Plotnitsky's reading of the poem is illuminating, but the poem's affinity with Heisenberg's physics is even more intimate than Plotnitsky suggests: the poem not only allegorizes the uncertainty principle; its fundamental dynamic is the uncertainty principle. Heisenberg's proposition that certainty (the ability to calculate one aspect of a physical phenomenon) results in uncertainty (the inability to calculate another aspect of the phenomenon), and that the amount of uncertainty can be measured, deconstructs that binary, as Shelley's poem illustrates.

In the opening stanza of "Mont Blanc," Shelley's desire to see the infinite as including the finite is reflected in the sudden shifts from one to the other:

> The everlasting universe of things
> Flows through the mind, and rolls its rapid waves,
> Now dark—now glittering—now reflecting gloom—
> Now lending splendour, where from secret springs
> The source of human thought its tribute brings
> Of waters,—with a sound but half its own.
> Such as a feeble brook will oft assume
> In the wild woods, among the mountains lone,
> Where waterfalls around it leap for ever,
> Where woods and winds contend, and a vast river
> Over its rocks ceaselessly bursts and raves. (1–11)

With lightning speed, Shelley moves from an "everlasting universe" to a "universe of things." Adroitly, the word *universe* serves both phrases, creating the impression that Shelley has glided seamlessly from the infinite to the finite. Since the "universe of things" both "Flows through the mind" and "rolls its rapid waves," it appears that the division between the metaphysical and the physical has been erased. In the fleeting impressions of the evanescent changes of this universe, "Now dark—now glittering—now reflecting gloom— / Now lending splendour," Shelley offsets the temporality implied by those changes with the insistent, atemporal "now." In a more conventional way, he presents the finite as infinite in the extended simile that concludes the stanza by uniting nouns of materiality with adverbs of eternality: the "waterfalls . . . leap for ever" and "a vast river / . . . ceaselessly bursts and raves." Shelley's rhetorical moves create a euphoric sense that the physical and metaphysical have been reconciled, making the materiality of the mountain immortal and the idea of the mountain tangible. On closer examination, however, the euphoria is not the byproduct of reconciliation between two ontological states but the result of the vertigo one experiences from the rapid shifts from one state to the other. When Shelley affirms the certainty of the physical mountain, the metaphysical mountain is elusive (uncertain), and vice versa.

The deconstruction of the finite-infinite binary is more personal in the second stanza. In an apostrophe to the ravine Shelley writes:

> . . . when I gaze on thee
> I seem as in a trance sublime and strange
> To muse on my own separate phantasy,
> My own, my human mind, which passively
> Now renders and receives fast influencings,
> Holding an unremitting interchange
> With the clear universe of things around. . .(34–40)

Once again, the certainty of one ontological state impels the uncertainty of the other. When Shelley's gaze on the mountain becomes a gaze into his mind, the two gazes do not converge into a single focus; they result in an "interchange" with the universe, a giving and taking of "fast influencings." To be accurate, Heisenberg's principle describes the asymmetrical dynamic between physical functions, while Shelley's poem portrays the asymmetrical dynamic between physical and metaphysical states. The structural equivalence between the two is, however, striking.

When Mont Blanc first makes its appearance in the eponymous poem, it is seen "piercing the infinite sky" (60). After musing on the geological history of the mountain, however, Shelley states, "all seems eternal now" (75). He then steps away from the mountain and observes:

> The wilderness has a mysterious tongue
> Which teaches awful doubt, or faith so mild,
> So solemn, so serene, that man may be
> But for such faith with nature reconciled. . .(76–79)

Kenneth Cameron notes that in a manuscript of the poem, the phrase "But for such faith" reads "In such a faith," signaling that the reconciliation between man and nature, mind and mountain, is achieved (Shelley, *Selected Poetry and Prose* 516, nn233–34). The two are reconciled, however, because the mountain has assumed a metaphysical status, as Shelley indicates at the close of the poem. In the final stanza Shelley distinguishes between the mutability of the natural universe, which he describes in the penultimate stanza, and what he imagines to be the immutability of Mont Blanc. The intonation of "now" in the first stanza is complemented by the incanted "there" of the last stanza, which asserts the mountain's undying state: "Mont Blanc yet gleams on high: —the power is there" (127); "the snows descend / Upon that Mountain; none beholds them there" (131–32); "Winds contend / Silently there" (134–35). Once again, however, Shelley reveals his comprehension of the mountain to be a function of probability. Though the snows descend on the mountain, they do so unseen; similarly, the movements of the wind are unheard. Without a witness to those actions, their certainty is countered by a measure of uncertainty.

In spite of the manner in which Shelley subverts his own musings throughout the poem, he sustains his effort to integrate mind and matter in the penultimate clause of the poem: "The secret strength of things / Which governs thought, and to the infinite dome / Of heaven is as a law, inhabits thee!" (139–41). The fulcrum of these lines—"the infinite dome / Of heaven"—is appropriately an oxymoron of constrained boundlessness, and as such, it exposes Shelley's balancing of the physical and metaphysical (things, thoughts; law, mountain) as a rhetorical act. He culminates his meditation, however, not with a final assertion but with a question: "And what were thou, and earth, and stars, and sea, / If to the human mind's imaginings / Silence and solitude were vacancy?" (142–44). In this final moment he circles back and echoes the declaration with which the poem begins: "The everlasting universe of things / Flows through the mind" (1–2). Though his refusal to surrender the "things" of the universe is consistent with his claim that the infinite includes the finite, in the end he circumvents the dilemma of the coexistence of the definite and indefinite by presenting both as noumena rather than phenomena. It might appear that in his final question, uncertainty vanishes. Whether taken as a rhetorical question or a straightforward query, it appears to elicit the response of "something" or "nothing." The question is framed, however, as a hypothesis, a "what if," which causes the question to simultaneously imply certainty and invoke uncertainty.

Unlike Coleridge, Keats, or Shelley, William Blake had little use for astronomy. In his Annotations to Thornton's translation of *The Lord's Prayer*, Blake refers to "a Lawful Heaven seen thro a Lawful Telescope," as if the scientific instrument were designed to regulate perception (*Complete Poetry and Prose* 668). In spite of his disdain for Herschel, whom he mocks in veiled allusions in his epic poem *Milton* (29.4–18), Blake reveals in his poetry unusually strong affinities with twentieth-century physics.[5] Like the other poets mentioned in this discussion, he rejects the differentiated/undifferentiated paradigm, as seen in his short political prophecy *Europe*, where he asks: "who shall bind the infinite with an eternal band? / To compass it with swaddling bands?" (2.13–14). In *Milton*, which is a corrective to *Paradise Lost*, he explores the idea of infinity in depth. The poem begins with a surreal scene: John Milton has "walkd about in Eternity / One hundred years," ruminating over his theological errors (2.16–17). As the poem progresses, Blake enters the narrative as a character and helps Milton correct those errors, chief among which is his belief that God is separated from humanity. As Milton begins his journey to theological and poetic redemption, Blake provides an alternative to viewing infinity as the endless extension of space:

> Seest thou the little winged fly, smaller than a
> grain of sand?
> It has a heart like thee; a brain open to heaven &
> hell,
> Withinside wondrous & expansive; its gates are
> not clos'd,
> I hope thine are not. (20.27–30)

After noting the "expansive" interior of the insect, Blake urges, "O thou mortal man. / Seek not thy heavenly father then beyond the skies" (20.31–32). Blake's humble instruction synchronizes with Coleridge's claim, noted earlier, that "We remove one surface [of matter], but to meet with another" (*Biographia Literaria* 133). Similarly, Blake's assertion in a letter, written in 1827, that an atom is "A Thing that does not Exist" (*Complete Poetry and

Prose 783) is in harmony with Coleridge's statement that "Matter has no *Inward*" (*Biographia Literaria* 133), which shows how remarkably close they were in their thinking about physics and metaphysics.

The synchronicity between Coleridge and Blake is even more acute when one compares their respective geometries of the universe. Coleridge writes in a note: "It surely is not impossible that to some infinitely superior being the whole Universe may be one plain—the distance between planet and planet only the pores that exist in any grain of sand—and the distances between system & system no greater than the distance between one grain and the grain adjacent" (*Notebooks* 1:120). Whereas Blake finds "a World in a Grain of Sand" ("Auguries of Innocence" 1), Coleridge finds the world (from "an infinitely superior" perspective) to be but a grain of sand. According to Coleridge and Blake, the conventional view of infinity, like the conventional view of God, venerates remoteness. In *Milton,* Blake indicates the poet Milton must surrender such veneration at every turn. As his rescuer, Blake articulates what he implies is the true physics of the infinite:

> The nature of infinity is this: That every thing has its
> Own Vortex; and when once a traveller thro Eternity.
> Has passd that Vortex, he percieves it roll backward behind
> His path, into a globe itself infolding; like a sun:
> Or like a moon, or like a universe of starry majesty,
> . . .
> Thus is the earth one infinite plane . . .
> (*Milton* 15.21–32)

Blake's and Coleridge's contemporaneous claims (both made around 1804) that the earth, or universe, is an extended flat surface (plain or plane) are striking, yet, at the time these claims were made, they were, to put it mildly, minority views. Two centuries later their assertions give one pause, however. In a discussion of the shape of the cosmos in the wake of a big bang, Brian Greene writes that the "example of infinite flat space is far more than academic. We will see that there is mounting evidence that the overall shape of space is not curved, and since there is no evidence as yet that space has a video game shape, the flat, infinitely large spatial shape is the front-running contender for the large-scale structure of spacetime" (249–50). Though infinite flat space is the frontrunner, one of the other contenders is also suggestive in light of Blake's cosmic vision. Earlier in his discussion of the shape of the cosmos, Greene admits, "whether space goes on forever or wraps back like a video screen—is still completely open" (243). In his depiction of infinity, Blake tracks a traveler through Eternity, who "percieves [his vortex] roll backward behind / His path, into a globe itself infolding," an evocative description when considering the possibility of space "wrap[ping] back like a video screen."

In a foundational study of Blake and physics, Donald Ault asserts, "[In] the vortex passage from *Milton* . . . Newtonian and Cartesian cosmology is transformed through optical analogies. In this process, vision, cosmology, and cosmogeny become perspectivistic" (160). The relationship between cosmology and optics in Blake is critical, as Ault indicates, but, as Lussier argues, the vortex also has a pragmatic role in the narrative: it "primarily functions in the poem as transportation for Milton from his place in 'Eternity' to Blake's place in 'Generation'" (*Romantic Dynamics* 85). Though I see a different itinerary in the poem—Milton, I would argue, is transported from a false view of infinity (remoteness) to a true view of infinity (immanence)—Lussier reveals close similarities between the trajectory and movement of Blake's vortex and phenomena described by contemporary physicists. There is, however, another aspect of Blake's description of the vortex that is arresting in view of present-day science: his claim that in infinity "every thing has its / Own Vortex" is resonant when one considers the hypothesis, advanced by some physicists, that there was more than one big bang. Greene writes:

> Normally, we imagine the universe began as a dot . . . in which there is no exterior space or time. Then, from some kind of eruption, space and time unfurled from their compressed form and the expanding universe took flight. But if the universe is spatially infinite, *there was already an infinite spatial expanse at the moment of the big bang*. At this initial moment, the energy density soared and an incomparably large temperature was reached, but these extreme conditions existed everywhere, not just at one single point. In this setting, the big bang did not take place at one point; instead, the big bang eruption took place *everywhere* on the infinite expanse. Comparing this to the conventional single-dot beginning, it is as though there were many big bangs, one at each point on the infinite spatial expanse. (249)

If indeed Blake addresses the nature of origins in his presentation of infinity, his assertion of a plurality of vortices may be his way of configuring a cosmos that did not emerge from a single event.

As the English romantic poets demonstrate and as their critics have observed, rejection of the mind-matter dualism is requisite for release from Newton's universe. In a discussion of Blake and twentieth-century physics, Lussier has argued, "The relationship of mind and matter . . . is a dynamic and complementary one" (*Romantic Dynamics* 96). He then expands his frame of reference by attributing this conception of mind and matter to other poets of the period: "The theoretical argument for mind/matter interpenetration, a mainstay within most Romantic poetics, has also moved to the foreground of attempts to quantize brain functions" (96). As he indicates, most critics who have observed an active engagement between mind and matter in romantic poetry have proposed that the poets create a means by which mind and matter can freely transfer their properties to one another. This analysis of romantic poets, and their scientific successors, suggests, however, that both groups circle back to Priestley. The quantizing of brain functions is the logical, if not inevitable, result of Priestley's contention that "what we call *mind* . . . is not a substance distinct from the body, but the result of corporeal organization" (355). On this point, I differ from Lussier and other critics. Though the romantic poets, like Priestley, reject the mind-matter dualism, unlike Priestley they do not conclude that such a rejection yields a mutual transference between the properties of each. With the exception of Keats (who does not address the subject), the other poets I have examined—Coleridge, Shelley, and Blake—arrive at a different outcome from the deconstruction of the mind-matter binary. Their ontological inquiries do not result in an interpenetration of mind and matter but in the surrender of matter to mind. The poets suggest that if we probe matter to locate its inner or outer limit, we find it consists of an infinite regression (or progression) of circumferences. Finitude, whether we name it atom or cosmos, proves to be not at all finite. In the view of these poets, it is, therefore, an illusion, which is displaced by infinity.

Though William Wordsworth does not wrestle with the ontology of matter per se, his learning curve leads him to a metaphysical view of the universe, which makes him a precursor of twentieth-century physics as well. In his early life, he defies the new astronomy and stands by the conventional view of the universe, evidenced in his description of "the glory of the heavens" (13) in "A Night-Piece":

> There, in a black-blue vault [the Moon] sails along,
> Followed by multitudes of stars, that, small
> And sharp, and bright, along with the dark abyss
> Drive as she drives: how fast they wheel away,
> Yet vanish not! —the wind is in the tree,
> But they are silent; —still they roll along
> Immeasurably distant; and the vault,
> Built round by those white clouds, enormous clouds,
> Still deepens its unfathomable depth. (14–22)

Though he presents the stars as moving, he counters the claim of their mutability, declaring emphatically that they "vanish not!" Characteristically, Wordsworth introduces spontaneity into his description by modulating his initial impression, the "white clouds" immediately being refined as "enormous clouds." The effect is lovely—a lyrical impression of a fleeting moment—but the evanescence takes place within an immovable, immutable vault. Any shifting of cosmic phenomena is contained, and the differentiated/undifferentiated paradigm remains intact.

In "Star-gazers," written several years after "A Night-Piece," Wordsworth reveals why he is able to preserve a conventional view of the heavens. He describes in the poem with disparagement a public viewing of the night sky through a telescope, portraying the instrument as a technological intrusion. The poem concludes on a melancholy note:

> Whatever be the cause, 'tis sure that they who pry
> and pore
> Seem to meet with little gain, seem less happy
> than before:

> One after One they take their turn, nor have I one
> espied
> That doth not slackly go away, as if dissatisfied.
> (29–32)

Wordsworth intimates that the atomizing of the universe depletes it of its soul and fails to recognize the immutability of cosmic phenomena, a view he maintains throughout his poetry.

Though Wordsworth never loses his wariness of the scientific treatment of the heavens as a specimen, his own view of the cosmos evolves from mystery to metaphysics by way of an attempted mediation between mind and matter. In "Lines Composed a Few Miles above Tintern Abbey," he famously tries to negotiate a middle ground between imagination and perception. Toward the end of his prismatic presentation of a beloved place, he declares:

> . . . Therefore am I still
> A lover of the meadows and the woods,
> And mountains; and of all that we behold
> From this green earth; of all the mighty world
> Of eye, and ear, —both what they half create,
> And what perceive . . . (102–07)

In much of his poetry, Wordsworth envisions collaboration between the physical universe and the mind, as Jack Stillinger has argued:

> In Books VI and VII [of Wordsworth's *Prelude*] we are shown ways in which the natural world leads the mind to an idea of something beyond nature: "The immeasurable height / Of woods decaying, never to be decayed, / The stationary blasts of waterfalls," and other images of permanence are seen as "types and symbols of Eternity"; and "the

> everlasting streams and woods, / Stretched and still stretching," and other impressions shape "The views and aspirations of the soul / To majesty." (Wordsworth, *Selected Poems and Prefaces* xvi)

The images of natural phenomena that are free from temporality recall Coleridge's "Motionless torrents! [and] silent cataracts!" in his meditation on Mont Blanc ("Hymn" 53), and they anticipate a discovery on Wordsworth's part that is similar to Coleridge's conclusion about the nature of matter. Though Wordsworth reveals in most of his poetry a reluctance to give up his stake in the material universe, he takes an uncharacteristic turn toward the end of his career. In the final book of the 1805 *Prelude*, he follows a majestic description of the landscape around Mount Snowdon with an admission that he has come to value it as a symbol:

> A meditation rose in me that night
> Upon the lonely mountain when the scene
> Had passed away, and it appeared to me
> The perfect image of a mighty mind,
> Of one that feeds upon infinity,
> That is exalted by an under-presence,
> The sense of God, or whatsoe'er is dim
> Or vast in its own being. . . . (13.66–73)

At the close of the epic, the symbol vanishes altogether, and Wordsworth, in an apostrophe to Coleridge, extols the mind directly:

> Prophets of Nature, we to [mankind] will speak
> A lasting inspiration, sanctified
> By reason and by truth; what we have loved
> Others will love, and we will teach them how:
> Instruct them how the mind of man becomes
> A thousand times more beautiful than the earth

On which he dwells, above this frame of things
(Which, 'mid all revolutions in the hopes
And fears of men, doth still remain unchanged)
In beauty exalted, as it is itself
Of substance and of fabric more divine. (13.442–52)

In these final lines, matter, which is inescapably mutable, recedes in the presence of the immutable mind.

Though Wordsworth culminates his epic with the ascendency of the human mind over the natural universe, it would be inaccurate to portray him as dismissing the enterprise of science altogether. In a discussion of the professional rivalry of the natural philosopher Humphry Davy and Wordsworth, Catherine Ross notes, "What we perceive today—that poets and scientists are radically different kinds of workers—is not a natural, but rather a constructed estrangement that was necessitated by the changing market for the products of these intellectual laborers during the Romantic Age" (24). In *The Prelude*, she reminds us, Wordsworth himself describes "bard and sage" as "Twin labourers and heirs of the same hopes" (5.41–43). In spite of the camaraderie Wordsworth portrays between the scientist and the poet, Ross reveals the tenacious competition that existed between Davy and Wordsworth. Indeed, as Ross points out, Wordsworth asserts at the close of his epic the superiority of the poet over the scientist. In a gloss of the lines quoted above, Ross writes:

> [Wordsworth] retools the word "labourer"—now he and Coleridge alone are described as "joint labourers" [13.439] and "Prophets of Nature" . . . [and] he also declares that they will "speak / A lasting inspiration," which is "sanctified" as much as any of Davy's inspiring scientific performances. . . . They will teach their fellows that "the mind of man," . . . this creative, *poetical* mind . . .

> is not only a "thousand times more beautiful than the earth," . . . it is also "*of substance . . . more divine*." (47)

Though no version of *The Prelude* was published until 1850, the sentiments of Wordsworth's 1805 *Prelude* were hardly a secret, and they were countered by Davy, who declared in his 1807 "Introductory Lecture to the Chemistry of Nature" that "men of science, instead of worshipping idols existing in their own imaginations, have examined with reverence and awe the substantial majesty of nature" (qtd. in Ross 40).

It might appear that Davy got the last word. His condescending claim—while poets imagine, scientists examine—affirms the longstanding priority the scientist's epistemological approach has been given over that of the creative artist. In more recent times, however, the authority of empiricism has been called into question by some physicists, who have acknowledged the significant role of the mind in scientific discovery. In a study of the correspondences between art and science, Bülent Atalay states:

> [The] scientist operates as if physical laws already exist, in unique form, and only need to be discovered, or to be extricated from nature. But in reality, the physical laws no more exist in unequivocal manner than the statue in [a] rough block. In the hands of different sculptors the block is destined to yield different forms. And in the hands of different scientists the laws are destined to emerge in different form, although ultimately perhaps susceptible to a demonstration of equivalence. (19–20)

Though Atalay qualifies his suggestion that physical laws reflect the mind of the scientist who discovers them, his characterization of physics is arresting in light of the metaphysical view of the universe presented by Wordsworth at the end of *The Prelude*, as well as by Wordsworth's contemporaries noted earlier.

If we were to deem the associations between English poetry around 1800 and twentieth-century physics as purely serendipitous, we would ignore the link the poets saw between their work and the scientific enterprise. In his "Defence of Poetry," Shelley proclaims poetry to be "at once the centre and circumference of knowledge," "that which comprehends all science," and "that to which all science must be referred" (503). As his manifesto draws to a close, he extols poets as "the mirrors of the gigantic shadows which futurity casts upon the present . . ." (508). The anticipation by early nineteenth-century poets of significant discoveries by twentieth-century physicists suggests that Shelley's heady claims may not be the exuberant overreaching of a literary artist. Yet to place poets in the vanguard of civilization overlooks the fact that it was a scientist and a philosopher, Herschel and Priestley, who openly challenged the differentiated/undifferentiated paradigm of the universe in the late 1700s. Their scrutiny of the longstanding paradigm created an imaginative space for the poets who followed, which enabled the poets to reconceive the universe. Locating the genesis of an idea and tracking its course through the minds of scientists, philosophers, and poets is a tantalizing goal but difficult to achieve. Rather than attempting to situate cultural agents in a linear fashion, it is perhaps more beneficial to see them operating in a vortex. Such was the case in England around 1800, when forward thinkers from different cultural arenas dared to rethink the nature of the universe, thereby providing a backdrop by which the twentieth century could bewitch the early nineteenth century with its shadows.

NOTES

1. In "A Wrinkle in Space," I have argued, "Newton gave the cosmos a shape it would retain for the next two centuries" (2). I further state in the article that "although significant scientific events occurred during this period, such as the discovery of the planet Uranus, Herschel and others primarily filled in the space already outlined by Newton" (4). Though it was Einstein who impelled a radical reconception of the universe when he formally challenged the concepts of absolute time and space, I contend in this essay that Herschel's discovery that the cosmos is mutable, along with his challenge to the differentiated/undifferentiated paradigm, contributed significantly to an evolving view of the universe.

2. Many of the plates of William Blake's illuminated poems are heavily populated with words, which has generated imaginative responses from critics. In "A Wrinkle in Space," I propose that Blake's unusual formatting may signal his resistance to the differentiated/undifferentiated paradigm (10–15).

3. In "Keats's Post-Newtonian Poetics," I explore the poet's experimentation with temporal and spatial parameters in three of his odes, including "To Autumn."

4. For another link between "Mont Blanc" and twentieth-century physics, see Mark Lussier's article "Shelley's Poetics, Wave Dynamics, and the Telling Rhythm of Complementarity," where he shows how the opening images of the poem describe the wave dynamics of superstring theory (93).

5. The allusions to Herschel's giant telescope in Milton are remarkably specific, as I note in "On Herschel's Forty-Foot Telescope, 1789." (See paragraphs 16 and 17.)

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Abraham Gottlob Werner
Money, Romance, Classification

ANDRE WAKEFIELD

> *It often happens that historians of science—and philosophers of science—flatter themselves that the discipline they study has always existed. They draw their subject matter from a variety of texts belonging to different epochs and to heterogeneous fields, and they plot the development of an imaginary object. The case of geology is an excellent example of this.*
>
> —*Paolo Rossi, The Dark Abyss of Time*

Though Abraham Gottlob Werner (1749–1817) died before the modern science of geology had really been established, that has not stopped historians of science and geologists from dubbing him a central figure in the history of geology. Not that there is anything unusual about designating disciplinary founders and precursors—it is so common that we hardly think about it any more. And yet it is problematic to project modern scientific disciplines back into the past, always searching for the beginnings of the present, for the origins of *our* time. To the extent we do it, we act like disciplinary preformationists, pretending that the modern sciences—our modern disciplinary map of knowledge—always existed, even in embryo, waiting to be discovered.

But there was nothing inevitable about the development of the earth sciences. Like other natural and human sciences, geology became what it is in unexpected and contingent ways. We often learn the most about the history of a science by approaching it indirectly and obliquely, and this is especially true of Werner. He was, on the one hand, at the very epicenter of the burgeoning "romantic science" movement that took shape around 1800, serving as inspiration for figures ranging from Novalis (Friedrich von Hardenberg) to Alexander von Humboldt.[1] He was, on the other hand, an almost archetypal example of Enlightenment science, with his dry-as-dust systems of mineral classification. For those of us who work on the history of the earth sciences, Werner's name calls to mind basalt formations and mining academies; for everybody else, his life and works probably raise a more fundamental question: why did people around 1800 care so much about rocks?

Abraham Gottlob Werner was at the center of a movement that created "the conceptual space, as it were, within which modern earth scientists can now do geohistory as a matter of routine and not even have to think about its possibility" (Rudwick 5). He was, in other words, one of the people who made modern geology *possible*. Part of creating that "conceptual space" involved the historicization of the earth. There emerged a new willingness to treat terrestrial history in the same way as human history, that is, as a contingent and unpredictable thing. Treating the earth essentially as a product of *history* was dramatically different from approaching it as the result of constant and immutable *laws of nature*. It is the distinction between what Stephen Jay Gould called time's cycle and time's arrow, between the "the intelligibility of distinct and irreversible events" and the "intelligibility of timeless order and law-like structure" (Gould 15–16).

The historicization of nature coincided with the transformation of practices in early modern historiography. Natural historians consciously used the new methods of human history and applied them to terrestrial history. In many cases, these new geohistorians were also writers and compilers of human history. Just as archives, coins, monuments, and the like were being used in new ways to document the past, so terrestrial historians began to look to minerals, beds, formations, and fossils as documents for reconstructing the history of the earth.

There is a danger here, however, of overstating the originality of Werner and his contemporaries: The transposition of historiographical techniques onto rocks and fossils stretches back at least to the seventeenth century. A century before Werner lectured in Freiberg, Gottfried Wilhelm Leibniz, at that time court historian to the House of Hannover, was working in the mines of the Harz Mountains. His *Protogaea,* drafted around 1693, used novel historiographical techniques to reconstruct the history of the earth. *Protogaea*, it is true, was one of many "theories of the earth" that appeared between 1660 and 1720. Most of these theories explained the formation of the earth in mechanical terms, speculating on the series of causes that led to its original formation. Because these "theories of the earth" attempted to reconstruct the past based on unchanging, universal laws of nature, they were essentially *not* historical. Leibniz's narrative, on the other hand, went beyond them, sketching elements of what we would now call stratigraphy, and reconstructing a unique historical series of events. Using his skills as a dynastic historian, Leibniz read the folds and layers of the earth to generate local narratives of the deep past.[2]

There are, nevertheless, important differences between Leibniz's historically inclined *Protogaea,* with its frequent conjectures and speculations about the deep past, and Werner's careful, painstaking classificatory works. Unlike the geotheorists of the late seventeenth and early eighteenth centuries, Werner had little interest in speculating about the first origins of the earth. Ironically, Werner is probably best known for his central role in the so-called Neptunist–Vulcanist debates. But this too is a misrepresentation. As Martin Rudwick explains:

> Historians and historically minded geologists have commonly ascribed the Neptunist system to Werner (and many of them, until recently, routinely castigated him for it). But Werner was merely giving his own expression to a widely held kind of geotheory, and he would have been the first to disclaim any originality in the matter. Only in his claim that basalts had originated as aqueous precipitates was he going against the general opinion of his geognostic contemporaries before he himself came on the scene. In any case, he regarded himself primarily as a sober descriptive geognost, not as a speculative geotheorist. (175)

In other words, Werner and his Vulcanist opponents shared a willingness to approach the earth's crust—its caves, formations, mines, volcanoes, rocks, minerals—as documents and archives for reconstructing the unique sequence of geohistory. In this sense, they were all working together to create a unique terrestrial history. The more profound rift, which would open at the end of the eighteenth century, divided these terrestrial historicists from the Plutonists, led by James Hutton (the so-called founder of modern geology), who imagined an endlessly cycling earth without beginning or end.[3]

Life and Works

Abraham Gottlob Werner came from a mining family. His father was an inspector for the Duke of Solm's ironworks in Wehrau (now Poland), where he earned enough money to provide the young Abraham Gottlob with a good early education. When his mother died, Werner left school to work for his father as a *Hüttenschreiber*, responsible for keeping the books, monitoring payroll, and assaying.[4] It was a lot of responsibility for a fifteen-year-old; he spent the next five years working there. After that, in 1769, Werner enrolled in the new Bergakademie Freiberg, which had been established in 1765. Werner spent the customary two years in Freiberg before departing for Leipzig to complete a law degree, so that he could qualify for service in the upper branches of Saxony's fiscal-mining state.

He remained in Leipzig until 1774 but never received a law degree, opting instead to study languages and philology. While at Leipzig, Werner wrote his first book, *Von den äußerlichen Kennzeichen der Foßilien*. Its publication in 1774 helped land him a job in Freiberg, where he still had connections. Karl Eugen Pabst von Ohain, an important official in Freiberg and Werner's former teacher, suggested to the directors of the Bergakademie that Werner receive a position as teacher of mining and curator of the mineral collection (*Mineraliensammlung*) there. Werner would remain at the Bergakademie for the rest of his life.

Werner was only twenty-four when he published his first book. The book's importance, both for Werner's own career and for the history of mineralogy more generally, is well documented.[5] It has been called the "first, comprehensive theoretical work on mineralogy in general," and it has taken its place as a canonical work for the young discipline of mineralogy (Guntau 43). *Von den äußerlichen Kennzeichen der Foßilien*, literally, "On the

External Characters of Fossils"—was intended not as a complete classification scheme but rather as a system for identifying minerals based on their external characteristics. The book was, of course, not about fossils in our sense, because in Werner's time the term *mineralogy* referred to a wider range of phenomena than it does today, extending to the entire mineral kingdom—that is, to rocks, fossils, *and* minerals (Rudwick 61). In fact, terminology was a big problem at this time, and it reflected the rapidly shifting parameters of the nascent earth sciences. Moreover, the nomenclature of these sciences reflected the existing structures of knowledge, which divided the study of the natural world into "natural philosophy" and "natural history." Within this larger field, however, Werner tried to establish several subfields. Mineralogy was simply knowledge of minerals *(Foßilien-Kenntniß)*; "mineralogy of mountains" *(Lehre von Gebirgen)* dealt with rock formations and their occurrence. Finally, "mineral geography" (*mineralogische Geographie*) was about the distribution of rocks, minerals, and fossils (Werner, *Von den äußerlichen Kennzeichen* 11–13).

Alexander Ospovat claimed that *Von den äußerlichen Kennzeichen der Foßilien* was "designed to aid the worker or the student in the field" ("Werner" 257). That may be true enough, but Werner was also concerned with larger questions of nomenclature and standardization. As Ernst Hamm has pointed out, Werner's early classification system, based on the external characteristics of minerals, actually worked to discipline the senses by providing "a fine-grained method for describing minerals, which relied upon sight, taste, touch, smell and even hearing" (Hamm 288). The system that young Werner was proposing was not unlike what Linnaeus had accomplished for plants and animals. Like Linnaeus, whose acolytes were many by the end of his life in the 1770s, Werner intended to provide a tool for cooperative labor by simplifying the dizzying array of mineral varieties that confronted mineralogists in the field (Körner 52–55). But it was more complicated than that, because Werner hoped to develop a more "natural" system than Linnaeus's, one in which nomenclature would conform, insofar as possible, to Nature herself. Young Werner showed extraordinary confidence, calling into question all existing systems of mineral classification and identification. And he was not afraid to name names. Some of the most prominent mineralogists and chemists of his time, among them Johan Wallerius and Axel Kronstedt, were not spared (Werner, *Von den äußerlichen Kennzeichen* 12–15).

Werner's main innovation—it was not his alone, but he was most responsible for its success—involved placing time at the heart of his mineral classification. Rejecting older methods that privileged location and composition, Werner made the rock *formation* his central organizing category. This meant, by implication, that his taxonomic system would be driven by discrete historical processes: it was now the time and mode of formation that became the central organizing category of his mineralogy. Werner's was, as Rachel Laudan has stressed, an "intrinsically historical" system of classification (Laudan 94–95).

However, as every practicing miner and dedicated geognostic savant knew, it was no easy thing to determine the time of formation. It was, in other words, not obvious to everybody that the principle of superposition—the principle that older rocks lie beneath younger rocks, as in sedimentary deposits—held universally. Werner, on the other hand, seemed to have few doubts. In his *Neue Theorie von der Entstehung der Gänge* (1791), Werner expressed confidence that the relative position of rocks could serve as a reliable indicator for their time of formation.

The Bergakademie Freiberg: The Fiscal-Administrative Context

Werner was one of a handful of savants—among them Horace-Bénédict de Saussure, William Hamilton, and Jean-André de Luc—who, toward the end of the eighteenth century, transformed our understanding of the earth and its formation (Rudwick 37). All of them had significant connections to the University of Göttingen and its famous Swiss professor Albrecht von Haller. But Werner's lifelong connection to the rich mines of Saxony's Erzgebirge gave him a different focus and perspective. In fact, the mines of Saxony, and the mining academy in Freiberg where Werner spent most of his life, provide *the* most important context for making sense of Werner's contribution. Unfortunately, the purposes of the Bergakademie, have been largely misunderstood. It was, as I shall argue in this section, *not* established to train "mining engineers" or technical experts. Rather, the Bergakademie Freiberg was created as a place to cultivate sophisticated fiscal-administrative managers, the future leaders of Saxony's Bergstaat.

The mining academies that sprouted up throughout the German lands during the second half of the eighteenth century provided first exclusive institutional context for research and instruction in the earth sciences.[6] The first of these mining academies, the Bergakademie Freiberg, founded in 1765, was also the most important of them. Werner and the geosciences he developed have become inseparably identified with the Bergakademie Freiberg, where he taught from 1775 until his death in 1817. In fact, Freiberg often appears in the literature as an appendage to *Wernerian geology*. In reality, however, the mining academy in Freiberg was much larger than Werner. Like every professor in Freiberg, Werner had to serve the interests of the Saxon (*Kursachsen*) fiscal state. That, and not the pursuit of knowledge, was the primary purpose of the Bergakademie.[7] Werner's works cannot be fully understood outside of this larger fiscal-administrative context. In fact, the purposes of the Bergakademie, as articulated by its founder Friedrich Anton von Heynitz, were part of a larger "cameralist" movement that sought to systematize and institutionalize training for fiscal officials in the German lands of the Holy Roman Empire.[8] Heynitz's correspondence with Saxon state officials demonstrates that the new mining academy sought to cultivate an entirely new kind of official. Heynitz intended, that is, to train skilled fiscal officials who could direct and manage Saxony's mines. As an early student at the Bergakademie, Werner was one of the cadets whom Heynitz hoped to train for fiscal-administrative service in the mines; later, as a professor in Freiberg, Werner was expected to inculcate those values in his own pupils.

During the second half of the eighteenth century, the cameralist, like the doctor or the lawyer, came to be seen as a particular kind of educated professional (Wakefield, "Police Chemistry"). Cameralist writers treated chemistry and mineralogy as integral parts of their young profession. These academic cameralists developed a system of "auxiliary sciences" (*Hilfswissenschaften*) to prepare young men for careers in the fiscal bureaus, police directorates, mining districts, and tax offices of the Holy Roman Empire. At the Kameral-Hohe-Schule in Lautern, for example, aspiring cameralists received extensive training in chemistry, mineralogy, technology and forestry (Plettenberg 95–99; 108–14). The Kameral-Hohe-Schule, and the "Lautern system" of cameral sciences which bore its name, was established in 1774, the same year in which young Werner published *Von den äußerlichen Kennzeichen der Foßilien*. Not incidentally, Werner, just then angling for a job in Freiberg, targeted cameralists as the primary audience for his first book:

> Eine der gemeinnützlichsten, und für die bürgerliche Gesellschaft fast unentbehrlichen Wissenschaften, ist die Naturgeschichte der Foßilien. Es ist zu bekannt, von was für Nutzen dieselbe für den Cameralisten, den Oeconomen, den Arzt, den Scheidekünstler, den Physiker, und den Philosophen ist, als daß ich dessen erst erwähnen sollte; und zudem wäre es auch hier wider meinen Zweck, dieser Wissenschaft eine Lobrede zu halten. (Werner, *Von den äußerlichen Kennzeichen* 13)[9]
>
> The natural history of minerals is one of the most widely useful sciences, being almost indispensable for civil society. How useful this science is for the cameralist, the oeconomist, the doctor, the chemist, the physicist, and the philosopher is so well known that I do not have to dwell on it; and it is moreover not my intention to hold a panegyric for this science.

By the time that Werner wrote these words, prominent cameralist writers and professors had been urging the establishment of mining academies for over three decades.[10] The first volume of Georg Heinrich Zincke's *Leipziger Sammlungen von Cammeral-Sachen*, for example, included an anonymous essay entitled "The profit and yields (*Der Nutzen und die Nutzungen*) of the mine; how such can be understood and improved according to the political and oeconomic principles of the *Kammerkollegium*." The essay sketched the plan for a mining academy, arguing that it would be the best way to improve the mines. Around the same time, Saxon Kommissionsrat Carl Friedrich Zimmermann sketched his own plan for a mining academy.[11] Zimmermann's preface concerned itself with the improvement of the mining sciences, which he considered the best way to increase yields. A new institution committed to the growth of the sciences and organized according to the best "cameral and oeconomic principles" would, he promised, yield millions for the sovereign treasury (Zimmermann, "Preface").

In 1746, Zimmermann published the *Obersächsische Berg-Academie*, in which he elaborated his plans for a mining academy (Herrmann 101–02, 114). The new institution, as envisioned by Zimmermann, would train fiscal administrators; the academy and its sciences would be strictly bound by cameralist considerations. Neither pure *Theoreticos* nor *Practicos* would be tolerated, nor would students learn how to function in Saxony's mining *Kollegien* as part of their training (Zimmermann 5–6). Moreover, Zimmermann devoted an entire section to "Mining Oeconomy" (*Berg-Oeconomie*), a notion whose key element was not work (*Arbeit*) but industriousness (*Fleiß*). *Fleiß* was not, on his view, an attribute of the miners themselves, but a result of good fiscal administration. Everything, that is, depended on a combination of good police ordinances, committed oversight personnel, and the multiple threads of visibility—the consciousness of being watched. *Fleiß* had to be manufactured. Perhaps that explains why Zimmermann considered one bad overseer to be better than ten good workers (" . . . ein Uebel Aufseher ist besser als zehen gute Arbeiter" [129–31]).

Johann von Justi, the most prominent cameralist writer of his generation, argued for the importance of mining academies in 1756. "That the mining sciences prosper," he wrote, "is not unimportant, and one must therefore provide good instruction in both universities and in special mining academies" ("Die Flor der Bergwerks-Wissenschaft träget hierzu nicht wenig bey; und man muß danenhero, sowol auf Universitäten, als auf besonderen Berg-Academien, guten Unterricht hierinnen veranstalten." [98]). Justi felt that the German lands, given their leading role in the mining sciences, should be the first to establish such institutions (98). Daniel Gottfried Schreber also began hatching plans for a mining academy and an "academy of oeconomic sciences" (*Academie der öconomischen Wissenschaften*) in the early 1760s.[12] He envisioned an academy for cameralists, separate from the university and with five professors who would teach cameral sciences, oeconomy, mathematics, physics, natural history, mineralogy, and chemistry. When Schreber was appointed as a professor at the University of Leipzig in 1764, he gave up his plans for a cameralist and mining academy. But the plan was not lost completely, for in the following year Schreber's good friend, Friedrich Anton von Heynitz, would found a mining academy in Freiberg.

Friedrich Anton von Heynitz came to Saxony in 1763, lured by the promise of a position on the Kammer- und Berggemach, Saxony's highest administrative body for mines and mining. Devastated by decades of war and mismanagement, Saxony was in the midst of a fiscal crisis when Heynitz arrived in Dresden. But Prince Friedrich Christian and a close circle of advisers, led by Thomas von Fritsch, had already begun to remake Saxony's administration. Among the first issues to be addressed by Fritsch and his fellow commissioners was the improvement of Saxony's mines.

"Mining," wrote Fritsch, "is undeniably one of the most important, if not the single most important, pillar of this land's welfare; its repair and maintenance, therefore, deserve the most exact reflection and the most thorough consideration" (Schlechte 218). Fritsch urged the preparation of a comprehensive balance sheet that would allow for systematic comparison of all income and expenditure related to mining. Such an overview, he argued, would demonstrate "how important mining is for the land, and how necessary it is to keep a diligent and watchful eye on the same" ("Der Bergbau ist wohl ohnstreitig eine und beynahe die vernehmste Grundsäule des Wohls dieser Lande"). Fritsch complained, moreover, that the mines had suffered from bad administration. Foreign investors had lost faith in Saxony's mines. Trust had to be reestablished through a mining administration marked by the "strict oversight of the sovereign." "We lose this trust," he explained, "if we appoint bad or dishonest officials" (Schlechte 218).

Considerations like these prompted the new elector, Friedrich Christian, to add a powerful new voice to the Kammer- und Berggemach in Dresden at the end of 1763. Possibly due to Fritsch's urging, the elector appointed Heynitz, an experienced senior mining official from Brunswick-Wolfenbüttel, as fourth mining councilor in the Berggemach.[13] Heynitz took up his new post in February of 1764. Unfortunately, the elector died suddenly during the following week, leaving his brother, Prince Xaver, as regent until the young heir, Friedrich August, came of age to rule. Xaver, however, soon fell out with Fritsch and his allies. Heynitz, for his part, encountered resistance from his colleagues in the Berggemach almost immediately upon his arrival in Dresden. He had wanted a leading role in Saxony's reorganization, with the right to report directly to the elector. Now, however, Heynitz found himself relegated to an advisory position, with little direct access to the regent or the secret council. Frustrated by his official position, Heynitz turned more and more to the Leipzig Oeconomic Society, where he devoted substantial time to mineralogy and metallurgical chemistry (Weber 116–19).

Heynitz was dissatisfied with his official position (Weber 116–19). In search of greater influence, he sent Cabinet Minister von Einsiedel a memorandum on the proposed reorganization of Saxony's mining administration on April 4, 1765 (StADresden, Loc. 1327, 1–7).[14] Heynitz wanted more personal control over the electorate's mines. He also suggested that members of the Oberbergamt in Freiberg, especially Oberberghauptmann von Oppel, be given a voice in Dresden's Berggemach. Their participation would, in his opinion, be an improvement over the useless *Medicos* and *Chymicos* in Dresden who directed the central mining administration.[15] Thanks largely to this memorandum, Heynitz was appointed "general commissioner of mines" (*Generalbergkommissar*) in June of 1765.

The new office did not give Heynitz complete control over Saxony's mining administration. Rather, many of his plans and projects remained subject to the approval of the Berggemach in Dresden (Weber 120–21). The new position did, however, give Heynitz considerable power over the Oberbergamt in Freiberg, placing him above even the Oberberghauptmann there. He thus turned his attention to the Oberbergamt, still animated by the dreams that had originally brought him to Saxony. It was at about this time, in the summer of 1765, that he seems to have embarked on a new approach. If he could not shape Saxony's mining policy from above, in Dresden, then he would reform it from within by taking control over the regional appointment and education of Saxony's mining officials. He would, that is, create a generation of officials in his own image.

On September 3, 1765, Heynitz sent a confidential memo to Count Einsiedel (StADresden, Loc. 1327, 21–24).[16] He expressed concern about the poor condition of the Oberbergamt. More particularly, he discussed the poor quality of the mining officials who worked there. Heynitz felt that the situation in Freiberg was chaotic and unacceptable. Since no one had a view of the whole, the state's mining "household" was in complete disarray. Heynitz proposed to remedy the situation through wholesale reorganization of the mining administration which, he argued, should be arranged according to the four natural divisions in the great economy of the mines: (1) mining proper, (2) stamping and separation, (3) smelting and assaying, and (4) accounting matters and acquisition of necessary materials (e.g., gun powder and wood). This form of organization would, in turn, allow officials to specialize. Each cadet could devote himself to one or another branch of the mining household (StADresden, Loc. 1327, 21–22). Heynitz urged Einsiedel to issue direct orders to the Berggemach about the reorganization. The new arrangement, he argued, would help to curb abuses and encourage industriousness, allowing for more effective oversight, since each official would be responsible for a discreet aspect of the mine (StADresden, Loc. 1327, 22).

Heynitz then turned to a specific enumeration and critique of the mining officials in Saxon service. Berghauptmann von Ponikau, at sixty-three, had "little life left in him." Mining Councilor von Wiehmannshausen was not only old, at almost sixty, but had been hampered by a "gouty foot" (*Podagricus*) for many years. Commissions-Rath Meybach was no better. He was also some sixty years old, and, with a smattering of knowledge in "speculative chemistry" and hydraulics, was quite worthless for the tough work of direction in a collegium. Mining Councilor Pabst von Ohain showed more promise. He had the requisite knowledge, insight, vigor, and zeal. Unfortunately, complained Heynitz, Ohain did not "seem wholly free of the passions, shows too much politics, never follows the truly straight path, doesn't allow himself to be led, and shows even less evidence of being able to lead others." All of this led Heynitz to the conclusion that there was a "real shortage of capable people to fill posts as *Berghauptleute* and mining councilors in Freyberg" (". . . den wahren Mangel tüchtiger Leute zu Berg Hauptleuten und Berg Räthen in Freyberg anzuzeigen" [StADresden, Loc. 1327, 22–23]). Heynitz then proposed a solution to the problem:

Es ist bey dem Freybergischen Berg Amte eine gewiβe *Stipendien Casse etablirt,* aus welcher Bergbedienten Söhne zu *Subalternen* Bedienungen Geld um das Markscheiden und probieren zu erlernen erhalten. Dieser *Fond* ist von groβem Nutzen, und ich habe bereits im Berg Gemach etliche mahl *proponirt,* hoffe auch endlich zu erhalten, daβ aus diesem *Fond* Leute die sich auf der *Mechanig* und andere dergl. Wiβenschaften legen, etwas beygeschoβen werden solle. Wie aber dieser *Fond* vor solche Leute nicht zureichend, welche die Bergwerks-Wißenschaft in der Absicht um den Hauβhalt *dirigiren* zu können, zu erlernen haben, wesfalls in Ungarn, Oesterreich, Böhmen, Schweden, und am Hartze stärkere *Fonds* ausgeworfen worden, ohne solche aber nicht leicht zu erhalten ist, das jemand dieses allemahl kostbahre *Metier* ergreiffen wird, so halte ich es pflichten halber vor höchst nöthig vorzustellen, daβ Sr. Königl. Hoheit erstere *Casse* mit einen Beytrag aus der Kammer zu dieser Absicht verstärcken mögen. (StADresden, Loc. 1327, 22–23, emphasis added)

The mining district in Freiberg has established a scholarship fund, from which sons of the state's mining officials can get money to learn subterranean surveying and assaying as training for subaltern positions. This fund is of great use, and I have already proposed many times in the Berggemach . . . that people who apply themselves to mechanics and other similar sciences should get something from this fund. But because this fund

> is not adequate for the *kind of people* who want to learn the mining sciences *in order to direct the household* (for which reason there are more considerable funds in Hungary, Austria, Bohemia, Sweden and in the Harz), and without which it is not easy to guarantee that anyone will take on this always costly profession, I see it as my duty to point out that His Royal Highness might see fit to increase the fund with a contribution from the treasury.

Heynitz was already preparing the way for a mining academy. The existing scholarship fund, which had been in place since 1702, no longer seemed adequate to him. It had been designed to provide narrow technical training for subaltern officials—in other words, training for the wrong type of official. His proposal, on the other hand, sought to provide funds for educating a completely different kind of mining official. It aimed, that is, at cultivating fiscal officials who could oversee, control and direct the mines.

Heynitz proposed a period of training to last three years. The first two years would be spent in one of Saxony's mining towns, probably Freiberg, with a scholarship of 200 Thaler per year. During this time, the candidate would study under the direct supervision of the *Oberberghauptmann*. In the third year, the scholarship would increase to 400 Thaler, and the candidate would begin touring mines outside Saxony. In certain respects, the proposal resembled the structure of the 1702 scholarship fund, which had provided state support for aspiring young assayers and subterranean geometers to learn trades from skilled subaltern officials. But Heynitz's plan was significantly different, because it aimed at cultivating high-level officials for service in central bureaus like the Oberbergamt, or even the Berggemach.

Heynitz not only planned to train a new generation of mining officials; he aimed also to weed out "useless" officials from Saxon service. He had, for that purpose, begun to prepare an overview, in tabular form, of salaries and other income for all of Saxony's mining officials. He also examined their orders, promising "that many official posts (*Bedienungen*) can be eliminated or combined." In other cases it was simply a matter of dumping old, tired, corrupt, and useless officials for a new generation of better ones (StADresden, Loc. 1327, 24). The success of the mines, he believed, depended on cultivating the right kind of mining official. In fact, Heynitz later claimed that the health of Saxony's mines rested completely on God's blessing and on the "diligence, insight, seriousness, application, liveliness and integrity of the land's mining and smelting officials."[17] He attributed the decline of mines in the Harz and the Hungarian Carpathians to the absence of good officials there. A small investment in the education of Saxony's mining officials, therefore, would directly benefit the sovereign treasury. "This proposal," he promised, "will soon yield a rich profit (*sich rentiren*), and your Excellency is already personally acquainted with the importance of Electoral Saxony's mines."

Only two months later, Prince Xaver and the elector's widow, Maria Antonia, visited Freiberg. Heynitz, hoping they would support his plans for a mining academy, put on a show (Weber 156–57). He had the mine shafts artificially illuminated and the miners' tools restored. He arranged demonstrations of ore stamping and separation. He ordered two officials, Christlieb Ehregott Gellert and Friedrich Wilhelm Charpentier, to perform chemical experiments.[18] And, perhaps most importantly of all, Heynitz arranged for a dramatic miners' parade to follow the evening meal. Xaver, who had a weakness for military processions, authorized Heynitz to write up a concrete proposal for the mining academy on the spot. Heynitz submitted his plan the very next day (StADresden, Loc. 514, 1–6).

Heynitz's plan for the new academy did not merely extend the purposes of the existing scholarship fund.[19] Rather, the new academy, as he envisioned it, would prepare young members of the nobility for careers in the upper echelons of Saxony's mining administration. Whereas the existing scholarship fund had been established to support the acquisition of technical skills, especially assaying and subterranean surveying, the new academy would provide broader training in natural history and natural philosophy. Cadets (that is, the students at the mining academy) were also expected to have legal training, and the plan provided for university study in jurisprudence, financed by the sovereign. Moreover, Heynitz strongly believed in the value of touring the mines, and his plan thus set aside almost half of the total budget for travel costs. He designed his new academy specifically to educate those officials who would staff Saxony's fiscal bureaus—especially the Berggemach and Oberbergamt—well into the future. Provided with noble titles, legal training, and well-placed connections from their extensive travel, the cadets were being groomed for positions in the upper levels of Saxony's administration. Unlike their predecessors, who had used the scholarship fund simply to learn specific skills, the Bergakademie had more ambitious goals. It would produce good cameralists to direct Saxony's mines.

The Bergakademie, as Heynitz had conceived it, posed a challenge to the universities. The task of educating officials for state service, whether in law, medicine, or theology, had traditionally been the exclusive province of university education. With its new mandate, the mining academy now began to train state officials of its own.[20] Moreover, Freiberg's increasingly systematic instruction in mineralogy and chemistry offered an alternative to university education, which typically treated these subjects as auxiliary sciences for the medical faculty (Meinel). But the liberation of these sciences from the medical faculty signaled at the same time their subordination to Saxony's Oberbergamt. The mining academy, that is, gave the state bureaus direct control over certain kinds of knowledge and bypassed the troublesome universities, with their special academic privileges and quasi-autonomous faculties.

Friedrich von Trebra, the Bergakademie's first student, benefited directly from Heynitz's efforts. Trebra had been in Freiberg a little over a year when he was called upon to direct the mines in and around Marienberg, an important mining district in the Erz Mountains. He was only twenty-eight years old at the time and was surprised by the appointment: "That I might be the person for this position did not even enter my thoughts, and I was extremely surprised when I received an order early one morning to meet General Mining Commissioner von Heynitz" ("Daß ich die Person zu dieser Stelle seyn könnte, kam mir wohl nicht in die Gedanken. Sehr überraschte es mich dahero, als ich eines Morgens ziemlich früh den Befehl erhielt, als bald zum General-Bergkommissarius von Heynitz zu kommen." [Trebra, *Bergmeister Leben* 20–21]). At the meeting, Heynitz and Oppel asked Trebra whether he would accept the position of Bergmeister—essentially head of the mines—in Marienberg. Trebra replied with a question, asking Oppel and Heynitz whether they really thought he was ready to serve as Bergmeister. Heynitz explained that Trebra's reputation as "diligent and honest (*rechtlich*)" was most important "since the mining officials, and with them the mines, had lost their good reputation with the public due to assorted misdeeds." Moreover, the Marienberg district had fallen so far that there was not much to spoil. If Trebra proved "diligent and industrious (*fleißig*)" and revived the condition and productivity of the mines, he could expect rewards and advancement in the near future (Trebra, *Bergmeister Leben* 20–22).[21] Trebra was appointed to such an important office at such an early age because, according to Heynitz, Saxony lacked the necessary number of acceptable mining officials. As Trebra put it, the existing officials did not have the requisite "knowledge (*Kenntniß*), application (*Thätigkeit*), and integrity (*Rechtlichkeit*)" for proper administration (Trebra, *Bergmeister Leben* 18).

Trebra's case sheds light on the purposes of the Bergakademie. Heynitz wanted the academy to do more than simply transmit knowledge. He intended it to serve as a vehicle for shaping personality, attitudes, and behavior. Students would learn not only the chemical principles of smelting but also the police principles of Saxony's mining ordinances; not only the principles of subterranean geometry but also how to coax more work out of recalcitrant miners. Most important of all, perhaps, they would be indoctrinated into the ways of the *Bergstaat*, which they would learn to take for granted. Occasionally, the implicit assumptions of this peculiar administrative culture became explicit. When troubles arose between Trebra and the Dutch investors he had lured to Marienberg, for example, he discovered "how difficult it would be to attach those republican merchants to our mining and our institutions" (Trebra, *Bergmeister Leben* 532).

It should be clear by now that the Bergakademie was no mere technical academy. Rather, it was an institution ruthlessly dedicated to maximizing revenues for the sovereign treasury (*Kammer*). But consistent yields from the state's mines depended on support from groups of investors (*Gewerken*), who provided much of the capital on which the mines depended for everyday operation. Success in securing investment from these investors depended, in turn, on the reputation of the mines. In order to garner interest and investment from *Gewerken*, mining officials worked constantly to secure the reputation of the mines. By his own admission, Trebra was not the most experienced or the most technically gifted student at the academy in 1767, when he was appointed Bergmeister in Marienberg. He was, however, from the best family, with excellent connections. This made all the difference to Heynitz, who determined that Trebra would be most successful at rebuilding the reputation of a fallen mining town.

The twenty-year-old Abraham Gottlob Werner arrived in Freiberg less than two years after Trebra's departure for Marienberg. Werner's success in securing a professorship may have had as much to do with his experience as *Hüttenschreiber* in Wehrau as it did with the publication of his 1774 book on the external characteristics of minerals. In any case, there can be no doubt that Werner came to understand the fiscal importance of reputation. More than three decades after his appointment to the faculty, he submitted a report to the authorities that extolled the Bergakademie, and his contribution to it, in exactly these terms.[22] Men of great importance, including the Prussian ministers Baron Stein and Count Reden, had heard his lectures in Freiberg. Mining officials from all over Europe and the Americas had studied with him. But Werner did not stop there. The academy, and by implication *his* lectures, had attracted money from wealthy foreigners. He had, in other words, used the sciences to fill the duke's treasury with foreign silver. Like the cameralists before him, Werner saw the Bergakademie Freiberg as a many-sided source of sovereign income. He understood that Saxony's silver came not only from the mines of the Erz Mountains but also from the eager hands of wealthy foreign students.

Werner's tenure in Freiberg, between 1775 and 1817, coincided precisely with the period in which the study of rocks and fossils expanded the reach of history into the deep past; this expanded sense of time became, simultaneously, an essential source of inspiration for romantic *Naturphilosophie*. Much was at stake, then, even in apparently straightforward efforts to classify rocks and minerals. It is therefore difficult to recover the intensity of feeling with which contemporaries read Werner's musings on the *Kurze Klassifikation und Beschreibung der verschiedenen Gebürgsarten* (*Short Classification and Description of Rocks*). This work, filled with common-sense suggestions, aimed to remove "the astounding confusion" that plagued the definition of rocks by providing "a clear definition and suitable classification" (". . . eine erstaunliche Verwirrung . . . Eine deutliche Bestimmung und schickliche Klassifikation derselben") of them (42). How could such concrete and pedestrian descriptive rules provoke romantic reveries? Werner's seemingly innocuous rules of mineral classification held deeper meaning for contemporaries because they appeared in an intellectual environment suffused with passionate interest about everything "primitive." In Göttingen, for example, the seminars were buzzing with interest in the origins of language, which came to be viewed as a product of history. Historical linguistics, in turn, suggested new approaches to the origins of society and culture (Carhart). Fossils and minerals thus became further evidence of "primitive" worlds before Adam. In short, Werner's geognosy tapped into a rising tide of enthusiasm about nature's historicity that swept the German lands during the 1780s (Laudan 100–02; Rupke 141–42).

Werner's writings and lectures were enthusiastically embraced, as wealthy and well-connected students from all over

Europe came to study and meet with him. This group included many of the most important geologists of the early nineteenth century, among them Jean de Charpentier, Leopold von Buch, Alexander von Humboldt, Jean-André de Luc, and Robert Jameson. And there were many more. The dissemination of Werner's ideas was so impressive that it became a virtual business by the 1790s. It was around this time that Werner himself complained about the unauthorized circulation of his transcribed lectures:

> " . . . da ich seit dem Anfange meines akademischen Lehramts meine Lehrvorträge so halte, daß sie füglich nachgeschrieben werden können, jeder besondere Lehrkurs auch wirklich vielfach nachgeschrieben, und mit den Manuskripten—die zwar fast insgesamt fehlerhaft, jedoch einige immer beßer als andere sind—bereits seit vielen Jahren nicht eben zu meinen Vergnügen, eine Art von merkantilem Verkehre besonders in Ausland getrieben wird." (*Neue Theorie* xxv–xxvi)
>
> . . . because I have been structuring my lectures from the beginning of my academic career in a way that they can be recorded, each special course has been recorded quite frequently, and with the manuscripts—which are often full of mistakes, but some of them are always better than others—a kind of mercantile exchange, especially abroad, has taken place for many years now that I do not particularly appreciate.

Despite the immense international interest in his ideas, not all of Werner's students followed his principles, and many disagreed fundamentally with aspects of his geognosy and mineralogy. Historians of science have thus found it difficult to speak of his influence in the same terms as, say, a Newton or a Descartes.

Rachel Laudan proposed the term *Wernerian radiation* as a way to distinguish him from these other canonical figures in the history of science: "Thus to say that someone was Wernerian is to say that a direct line of influence can be traced back to Werner by personal contact, education, reading, or any of the other ways in which one scientist learns about another's work. . . . The term *radiation* does not suggest that all Werner's followers adopted the same set of his claims or that they all modified the same set of claims" (Laudan 105). Regardless of how we define Werner's influence, one thing is clear: at the end of the eighteenth century, he was *the* single most important source of geohistorical thinking.

If Werner's contribution to early geohistory was unparalleled, his ability to inspire German romantics was remarkable. He counted among his students Friedrich von Hardenberg (Novalis), Henrik Steffens, and Gotthilf Heinrich von Schubert. And yet there was nothing very romantic about Werner. "Romantic science," after all, is supposed to involve reflection and self-understanding (if not self-absorption), a keen aesthetic and poetic sense, hostility to all forms of mechanism, and an appreciation for the organic unity of Nature. Novalis's *Lehrlinge zu Sais,* "a paradigm of high Romanticism," contained all of these elements (Cunningham and Jardine 2–5). Werner's writings, by contrast, contained almost none of them. But, of course, it was Werner and the mines of Freiberg that famously inspired Novalis.

Novalis's first impressions of Freiberg were not good. He wrote August Wilhelm Schlegel on Christmas Day, 1797: "everything in Freiberg is empty and bleak." ("In Freyberg ist hierinn alles leer und kahl—kein fortstrebender Kopf—indeß soll mich Briefwechsel schadlos halten"). There was, he complained, no strong personality or impressive intellect to hold his attention. Letter writing would have to do (4:240). This would eventually change, as Hardenberg found the personality he had been looking for in Werner. In his unfinished novel, *Heinrich von Ofterdingen* (1802), Novalis portrayed Werner as a wise old teacher and miner.

> Mit tiefen Einsichten war er begabt, und doch kindlich und demütig in seinem Tun. Durch ihn ist das Bergwerk in großen Flor gekommen, und hat dem Herzoge von Böhmen zu ungeheuren Schätzen verholfen. Die ganze Gegend ist dadurch bevölkert und wohlhabend, und ein blühendes Land geworden. Alle Bergleute verehrten ihren Vater in ihm, und solange Eula steht, wird auch sein Name mit Rührung und Dankbarkeit genannt werden. Er war seiner Geburt nach Lausitzer und hieß Werner. (1:245)
>
> He was endowed with deep insight and yet childlike and modest in his actions. Through him the mines became successful and have secured immense treasures for the Duke of Bohemia. The entire area is populated and wealthy; it has become a flourishing region. All miners venerated him like a father, and as long as Eula exists, his name will be mentioned with love and gratefulness. He was born in the Lausitz and his name was Werner.

In Novalis's narrative, Werner's childlike love of nature, combined with keen observational skills, gave him intimate understanding of the caves and vaults and layers of the earth. This in turn allowed him to discover the true meaning of history in the subterranean terrestrial world, a lost *Urwelt* in which youthful Nature had once produced incredible marvels (Rupke).

But there is another, less recognized element in the romanticization of Werner—namely, Novalis suggests that Werner's knowledge of nature created prosperity for the miners, who regarded him as a beneficial father figure and provider. By the end of the eighteenth century, however, this was a very difficult case to make. After years of conflict between miners and the state's mining administration—and Werner, as an inspector of mines and professor at the Bergakademie Freiberg, was certainly part of Saxony's mining administration—mining officials were more likely to be viewed as antagonists than as friends of workaday miners. Novalis here seems to be harking back to the legendary silver yields of the mid-sixteenth century, the age of Georg Agricola, when (so legend had it) the territory's rulers and officials cared for their miners like fathers for children. By the end of the eighteenth century, however, the watchword was efficiency, and that relationship had changed irrevocably.[23]

By the 1760s, powerful mining officials like Friedrich Anton von Heynitz and Friedrich Wilhelm von Reden had already started to transform the mines of the Harz and Erz Mountains by instituting systematic regimes of increased oversight and efficiency. These men, with their attention to administrative detail and commitment to long-term improvements, were largely responsible for Saxony's increasing silver yields during the second half of the eighteenth century (Soetbeer). It is no accident that the Bergakademie Freiberg was founded during this same time, because it was part of the larger plan to reinvigorate the mines by training a generation of dedicated mining officials. These same officials were not expected to have special feeling for the common miner or for the bowels of the earth; rather, they were servants of the sovereign treasury (*Kammer*), whose interests they served. They were in that sense part of the larger cameralist tradition in Freiberg.

Friedrich Wilhelm Heinrich von Trebra and Abraham Gottlob Werner were part of this cameralist tradition: they were roughly the same age, both were students at the Bergakademie

Freiberg during its early years, and both rose to important positions in Saxony's mining administration. And yet they were very different men; those differences have left their traces in the published works. Werner's books were systematic, painstaking and physically unimpressive. His 1787 *Kurze Klassifikation und Beschreibung der verschiedenen Gebürgsarten*, for example, is no more than a pamphlet. Werner frequently complained about having no time and made frequent excuses for his slapdash writing style. Trebra was the opposite. His 1785 work, *Erfahrungen vom Innern der Gebirge,* was beautiful (see fig. 1; Rudwick 86). With its hand-colored engravings, evocative descriptions, and intimate writing style—Trebra composed the work as a series of letters to his friend, August Ferdinand von Veltheim—the large folio *Erfahrungen* constitutes a fine example of romantic science. Trebra made it clear that the beauty of the engravings was a central part of his argument. Though not as dramatic as the volcanoes of Italy, the German regions had their charms, and he hoped to convince the "public" about the truth of his argument by reproducing these formations in ideal fashion.

Despite the beauty of his presentation, Trebra's theory about the formation of veins was eventually overcome by Werner's, which appeared six years later, in 1791. Trebra, like his good friend Goethe, had emphasized the transitions between formations, focusing on slow, gradual processes of "fermentation" (*Gährung*) in the earth (Hamm 289, 298–300; Trebra). Werner, however, rejected this approach, proposing instead a straightforward "new theory" about the formation of veins: "All true veins were originally (necessarily) open fissures, which were later filled in from above." ("Alle wahre Gänge sind wirkliche, anfänglich (nothwendicherweise) offen gewesene, und nachher fast blos von oben herein ausgefülte, Spalten" [Werner, *Neue Theorie* 51.]) But the fate of this particular theory is perhaps less important than the approach that Trebra championed, for his *Erfahrungen vom Innern der Gebirge* was the harbinger of geology's future as a romantic science.

NOTES

1. On romantic science, see for example the collection of essays in Cunningham and Jardine.

2. On Leibniz's *Protogaea* and theories of the earth, see Cohen and Wakefield, "Introduction," xix-xxv.

3. See Rupke 251.

4. Wehrau (today Osiecznica, Poland) was part of the larger region of Upper Lusatia (Oberlausitz). It is located about 120 kilometers northeast of Dresden. The town was a center of glass and iron production during Werner's time.

5. See, for example, Guntau 18–19.

6. See, for example, Rudwick 23–26, 84–90; and Laudan 87–112.

7. On the fiscal imperatives of Werner's Freiberg, see Wakefield, "Cameralist Tradition in Freiberg."

8. For more on the cameral sciences and administrative practice, see Wakefield, *The Disordered Police State*.

9. "Cameralist" is mistranslated as "legislator" in Carozzi's 1962 English translation. See Werner, *On the External Characters*, xxiii.

10. For more on this connection, see Weber 152–54.

11. Zimmermann mentions this in his preface to Henckel.

12. See Schreber 10:417–36; Weber 154; and Tribe 91–94.

13. On Heynitz's appointment and activities in Saxon Service, see Weber 116–67; Baumgärtel, "Absolutismus" 67–99; and Schlechte 72–75.

14. *StADresden* refers to Sächsisches Hauptstaatsarchiv Dresden.

15. See StADresden, Loc. 1327, 1–7; Weber 129; and Baumgärtel, "Absolutismus" 71.

16. For another interpretation of its meaning and significance, see Weber 157.

17. Heynitz to Elector Friedrich August, 27 January 1769, StADresden, Loc. 36216, 2.

18. Both would later become teachers at the mining academy.

19. For this view, see Baumgärtel, "Vom Bergbüchlein zur Bergakademie" 142-44. Weber takes a different view (156).

20. Though many of the Bergakademie's students also attended the university, the mining academy began to usurp some of the functions that university education had once provided.

21. See also his recollections in *Erfahrungen* 187–90.

22. See Freiberg, Akte OBA 7917, 1: 231–33.

23. The best overarching account of this change, though focused on the Harz Mountains, appears in Bartels, *Vom frühneuzeitlichen Montangewerbe zur Bergbauindustrie*.

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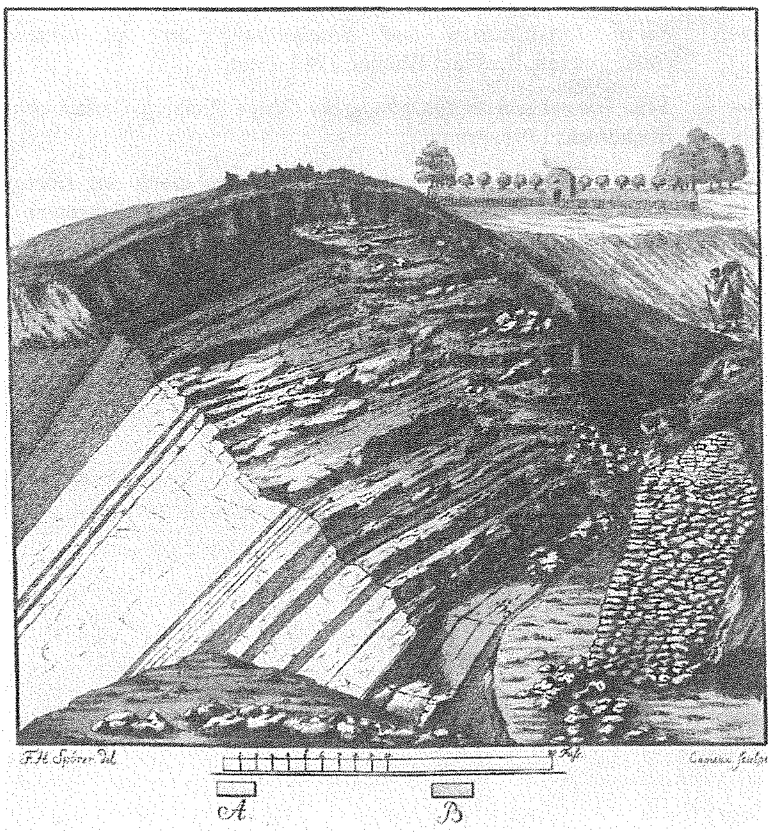

Friedrich Wilhelm Heinrich von Trebra, *Erfahrungen vom Innern der Gebirge nach Beobachtungen gesammelt* (Dessau und Leipzig, 1785). The illustration shows the layers of rocks in the Harz-Mountains in the vicinity of Clausthal. This hand colored engraving represents for Trebra the beauty of the depths of the earth.

The Physics of Coleridgean Romanticism

DOMETA WIEGAND BROTHERS

> *Bust of Leibnitz.—impressed on my whole soul a sensation which has ennobled and enriched it!—It is the face of a God!—& !—& Leibnitz was almost more than a man in the wonderful capaciousness of his Judgment & Imagination!*
>
> *—Samuel Coleridge, Coleridge's Letters*

In *The Idea of Progress in Eighteenth-Century Britain,* David Spadafora attests to the influence of Newton and Locke on British thought during the period. Spadafora carefully outlines how the methodology of these two thinkers grew to be held up as "the only one through which the various disciplines could achieve the desirable status of sciences . . . not until the true emergence of Romanticism at the very end of the century, among men like Blake and Coleridge, were these intellectual heroes and this outlook seriously challenged" (9). Spadafora strikes at the heart of the paradigmatic shift in British thinking that occurs in England at the turn of the century, and he rightly credits thinkers, such as Coleridge, for their dissemination of alternate views. It does, at first glance, seem strange to see poets put forth as the purveyors of ideas challenging the scientific establishment. If we begin to reconstruct the work and influences of the poet Coleridge, however, just such evidence of the origin of alternate worldviews manifests from the reconstruction of historic context. In fact, much of what is today considered contemporary thinking in the humanities and sciences can be traced to the stirrings of Romanticism.

The twenty-first century eye can see startling thought experiments in the poems of the day. One such example might be the poem "Coeli Enarrant," which emerges from Coleridge's Notebooks with an interesting treatment of space and time in the lines:

> And Time Drew out his subtle
> Threads so quick. That the long
> Summer's eve was long one whole web,
> A Space on which I lay commensurate. (2:3107)

Here time and space are conflated to a fourth dimension in which the fabric of space is woven from threads of time. Work completed on Coleridge's forward-looking astronomical notes and ideas as well as on specific readings of the poems suggests the bold theoretical implications of the above lines (Wiegand 95–96). Further consideration of the astronomical references however, raises other issues as to whether this "relativism" was limited to ideas of astronomy or if it applied to Coleridge's overall system of belief about the physical world. Did these relativistic cosmological ideas correspond to his basic system of logic, or were these ideas isolated? Certainly this distinction is important when examining a poet like Coleridge, who unsuccessfully labored his entire life in the quest for a philosophic "theory of everything" to unite the metaphysical and physical worlds. Furthermore, one might wonder on what basis Coleridge would have based a relativistic theory of the universe, with all of its attendant complications, especially in Newton's England. More than anything, all

Coleridgeans must resist the impulse to portray Coleridge as omnicompetent, despite the way his catholic interests, including the sciences generally and physics in particular, are reflected in his poetry.

The reflection of physics principles of the eighteenth and nineteenth centuries in canonical Romantic poetry has received critical attention in recent years. Newton's grip on science and his literary influence in the England of this period has attracted investigation by literary scholars. The rejection of Newtonian concepts among Continental and English Romantics such as Goethe has also undergone critical examination—Fred Burwick's *Damnation of Newton* is a good example. What is more, the criticism of scholars like Mervyn Nicholson has painted the Romantic poets as prefiguring some of the most radical particle physicists, such as theorist David Bohm. The critical gaze has uncovered the English Romantic poets' dissatisfaction with Newtonian principles and probed philosophical connections to twenty-first century science. Between Newton in the seventeenth and eighteenth centuries and Bohm in the twenty-first lies the physics of the relativistic universe of Einstein and, I believe, Coleridge.

If around the year 1800 this English poet possessed a relativistic view of the physical world in a solidly Newtonian England, he clearly based that view on some other minority explanation of physics available during the time. Investigating this explanation of Coleridge's worldview leads necessarily to the state of physics during the late eighteenth and early nineteenth centuries. The history of the legacy of physics in this period is largely the history of the work of two great titans of science: Isaac Newton and Gottfried Wilhelm Leibniz. Leibniz's name, in connection with Newton's, is familiar to scholars as the rival in the invention of the calculus—a scientific debate that still smolders in some quarters. But another debate between them (or at least between Leibniz and Newtonian apologists) concerns the makeup of the physical universe in time, space, and matter. The nature of physical matter and the relationship of time, space and motion, which were far from established facts at the end of the eighteenth century, were intimately tied to the strong religious philosophies of both Leibniz and Newton, just as these concepts were similarly tied together for Coleridge.

Coleridge criticism has long labored to reconstruct the relationship between his philosophy and his poetry. Coleridge's philosophy sought to describe the physical and metaphysical worlds, especially as they intersect at the junction of human imagination. As early as 1924 Alice Snyder remarks in her article "Coleridge's Cosmogony: A Note on the Poetic 'World-View,'" for Coleridge "Mass, Motion, and position were . . . so mutually involved that any fundamental creative principle must account simultaneously for all of these elements" (622). Snyder points to Kant's influence in Coleridge's development of this "mutually involved" relation of mass and motion as it contributes to his aesthetic worldview, manifest in his poetic production. Notwithstanding Snyder's fine early work, Coleridge's worldview is also clearly stamped by the influence of Leibniz, particularly in association with Leibniz's debate with Newton as to the nature of time, space, and matter.

The crux of this debate was formed in a series of letters outlining each man's system, exchanged between Leibniz and Newtonian apologist Samuel Clarke in 1715 and 1716. This debate discusses key issues important to Coleridge's development as a writer, specifically the role of God in the universe; whether space and time are absolute or relative, divisible or indivisible; and the nature of matters such as the existence of atoms and vacuum. These basic notions of physics mark the difference between an absolute, mechanistic version of the universe and a relativistic, even proto-Einsteinian vision. For brevity's sake, I must radically summarize the principles at stake. This correspondence shows that in Newton's systematic description of the universe (1) space is absolute and it is empty (a vacuum), a sort of container over and above the bodies it contains; (2) matter is composed of finite hard particles that cannot be divided and have no motion; and (3) space exists as a kind of "sensorium," an organ of God that he uses to watch over and adjust the mechanics of the universe, in order that Newton's mechanistic "clockwork" universe not wind down. In contrast, Leibniz's replies assert that (1) God's role in Newton's system is at best a *deus ex machina* and at worst pantheistic (possibly leading to atheism); (2) there is no such thing as a completely empty vacuum, or indivisible nonmoving particles of matter; and (3) space and time cannot be absolute (this view would privilege one particular frame of reference without sufficient cause) but are dependent upon relative relationships.

Of course we know which system prevailed in England in the eighteenth and early nineteenth centuries, before and during Coleridge's life and for a century after. The reason is quite clear—Newton's system accurately describes the movements of bodies and seems to confirm our perceived experience. As theoretical logic, however, it presents serious problems in dealing with concepts of infinity and change in relations, which are two topics crucial to Coleridge that will be addressed later. Despite being a minority opinion (one Einstein would later call a "lone voice" against absolute space), Leibniz's system influenced the formation of metaphysical logic in Coleridge's prose writings and came to aesthetic fruition in his poetics.

The influence of Leibniz on Coleridge is both direct and indirect. It is generally accepted by scholars that Coleridge came directly into contact with Leibniz in 1798–99 (Wordsworth 42). There may certainly have been undocumented earlier direct contact and certainly there was indirect influence on Coleridge. The nature of the feud between Leibniz and Newton adds to the diffusion of influence, as the two scientists were not the only players in this drama. Each man had disciples who both egged on both the combatants and each other. Many letters and papers hurled insults and allegations, often behind a veil of anonymity. Newton himself rarely answered charges directly in his own name but certainly influenced and even composed some of the answers given by his apologists, those willing to be named and those unwilling. The central letters between Leibniz and Samuel Clarke were only a taste of the propaganda circulating. James Gillman, Coleridge's physician, friend, and biographer points directly to one pseudonymous influence. Gillman says the formation of Coleridge's metaphysics was "occasioned by the essays on Liberty and Necessity in Cato's letters" (qtd. in Jasper 24). "Cato," as David Jasper points out, was the pseudonym for one John Trenchard, a political essayist, one of the combatants disseminating writings about the arguments swirling around Newton, Clarke, and Leibniz (24). This controversy between these systems of physics (and expanded metaphorically by writers to account for political and religious doctrines) was a catalyst that occurred early in Coleridge's development, significantly earlier than other important German influences, such as Coleridge's 1804 reading of Kant's *Cosmology*, as pointed out by Snyder. In fact it would have been difficult, considering the number of disciples and apologists writing on the subjects, for the young Coleridge, fascinated with religion, science, and philosophy to have avoided the controversy. As Gillman points out, we know the poet did not. There is every reason to believe that, both indirectly and directly, Leibnizian thinking surrounded and influenced Coleridge early on and that this effect continued throughout his life.

One possible manifestation of this influence is the use of many of Leibniz's terms in Coleridge's early poetry, including reference to "monads," an appeal to "universal harmonies," and the principle of the cause of sufficient reason. Several critics have proposed sources from Andrew Baxter to Joseph Priestley and Ralph Cudworth for the terminology and ideas in the poem "Religious Musings."[1] Certainly Coleridge read all these authors between 1794 and 1796. The influence of these authors on Coleridge, however, does not preclude the influence of Leibniz. Especially since Cudworth was certainly read by Leibniz by 1689 (Phemister and Brown 6–7), at the very least Coleridge and Leibniz were sharing reading influences. These influences occur very early in Coleridge's career (Kaufman 318–20). The particular usage of *monads* points to a specifically Leibnizian reading in distinction from Cudworth's usage. In "Religious Musings," Coleridge writes:

> Roll through the grosser and material mass
> In organizing surge! Holies of God!
> (And what if Monads of the infinite mind. (407-409)

Many have read these lines as inherently only pantheistic or Unitarian; however, they also reflect ideas of simple substance, entelechy, and aggregation—all of which are squarely Leibnizian, straight from his work "The Principles of Philosophy; or, the Monadology." In "The Monadology," monads are defined as "a simple substance that enters into composites" (68). These simple substances are entelechies that bind together in a plenum (for Leibniz, as important in his physics as his metaphysics). This aggregation is synonymous with Coleridge's "organizing surge," for, as Leibniz remarks, if considered individually without aggregation, "Monads all go confusedly to infinity, to the whole; but they are limited and differentiated by the degrees of their distinct perceptions" (77).

These lines read through the lens of monadology show less a narrowly pantheistic vision in which the world is God than a world in which God's creation is a plenum of motion and matter, and in which entelechies participate and are "interconnected" (77). One striking passage of this section of "The Monadology" goes on to say, "everybody is affected by everything that happens in the universe . . . [and] can read in each thing what happens everywhere. And even what has happened or what will happen, by observing in the present what is remote in time as well as in space" (77). If "The Monadology" influenced "Religious Musings," then this establishes a very early point for Coleridge's exposure to Leibniz's principle thoughts regarding the view that a human intelligence has access from the present to various points in time and space—or the idea that past, present, and future are coexistent.

These Leibnizian principles should be not only considered metaphysical terms that Coleridge adopted but also examined as tests of physics. Metaphysics proper is the endeavor to understand the nature of reality and thus subsumes the field of physics, particularly during the eighteenth and early nineteenth centuries. Most particularly, Leibniz's physics is a subfield of his metaphysics and was guided by a very strict logical principle: the cause of sufficient reason. This principle was used to rather devastating affect in the Leibniz–Clarke letters to reveal defects in Newton's argument regarding the orientation of space. Leibniz asserts that there is no reason that one frame should be chosen over another, as God could have easily reversed time itself, or east to west, for example, and Newton's system depends upon a privileged framework. Leibniz writes, "I hold space to be merely relative as time is" (61) and "the hypothesis [that space and time are absolute] is contradictory, that is 'tis an impossible fiction" (101). He continues, "I don't admit in matter, Parts perfectly solid, or that are the same throughout, without any variety or particular Motion in their parts, as the pretended atoms are imagined to be.

To suppose such bodies, is another popular opinion ill-grounded" (175). Leibniz's logic is radical for the time; he even postulates that, in order to determine position in space, one needs to know coexistent relationships and motion (197) and equates the transmission of light and its energy with matter (185). His system, in retrospect, seems almost prescient of Einstein's theory of relativity. Einstein even acknowledges the same difficulty with Newtonian methodology when he writes in *The Meaning of Relativity:*

> The laws of physics could be expressed, even in case there were a preferred direction in space, in such a way as to be co-variant with respect to the transformation (3); but such an expression would in this case be unsuitable. If there were a preferred direction in space it would simplify the description of natural phenomena to orient the system of coordinates in a definite way with respect to direction. (18–19)

This difficulty that cause of sufficient reason has in accounting for space orientation is one of a number of difficulties that Coleridge shares with Leibniz and, more than one hundred years later, with Einstein.

In his system, Leibniz finds one element of the Newton/Clarke argument particularly disturbing. Clarke, speaking for Newton, several times refers to space as a sensorium of God. Leibniz agues that this pantheistic view would eventually lead to atheism. This same view is later taken by Coleridge in his *Literary Remains*, regarding an annotation of Waterland's "A Vindication of Christ's Divinity: being a defence of some queries relating to Dr. Clarke's scheme of the Trinity." Coleridge states:

> As to Samuel Clarke the fact is every generation has its one or more overrated men. Clarke was

> such in the reign of George I; Dr. Johnson eminently so in that of George III. Lord Byron being the star now ascendant. In every religious and moral use of the word God taken absolutely, that is not as a God or the God, but as God, a relativity, a distinction in kind omni-quod non est Deus, is so essentially implied, that it is a matter of perfect indifference, whether we assert a world without God or make God the world . . . Whatever you mean by, or choose to believe of, the world, that and that alone, you mean by and believe of, God. (223–24)

Here, in addition to using the *Oxford English Dictionary*'s first recorded instance of "relativity," Coleridge clearly responds on the side of Leibniz as opposed to that of Newton/Clarke, as Clarke and Newton define absolute space as a sensorium or organ of the deity. Absolute space in Newton's system is faulty, as Leibniz observes, because "nothing will be easier than to account for anything bringing in the Deity, *Deum ex Machina*, without minding the nature of things" (263). Coleridge sees the Newton/Clarke position of space as a sensorium as equal to pantheism in which we "make God the world." Coleridge's further statement, that what you believe of the world is what you believe of God and vice versa, is very telling. By his own logic, if Coleridge believes God is a "relativity," then the world also reflects a relativity. The *Oxford English Dictionary* defines this instance of the use of "relativity" in *The Literary Remains* as only the "condition of being relative" and robs it of its context—in a debate about the nature of the physical world—and therefore of any scientific association, reserving that distinction for an 1882 entry by Maxwell.

Coleridge spent a great deal of time exploring the ideas in both Leibniz's and Newton's cosmologies of matter and movement, space and time. The atomistic, absolute vision of Newton's was one that Coleridge found deeply disturbing. He, in England, was a lone voice against the megalith of Newtonian mechanics, as Leibniz was on the Continent before him. Seth Watson makes this clear in his introduction to the 1848 edition of the *Theory of Life*, entitled there as *Hints towards the Formation of a More Comprehensive Theory of Life*:

> The prevalent natural philosophy of the present day is that which is called corpuscular, because it assumes the existence of a first matter consisting of corpuscular or atoms, which are supposed to be definite, though extremely small, quantities invested with qualities of extension, impenetrability, and the like; and from certain combinations of these qualities, Life is considered by some persons to be a necessary result. This philosophy Mr. Coleridge combats. (11)

The *Theory of Life* is not limited strictly to biological concerns. The nature of matter as addressed above shows his interest in physics. Coleridge spends time setting up ideas of matter and space and time relations. These relations are the basic philosophical questions necessary for a cause of sufficient reason. As for the Newtonian view of matter in conjunction with absolute space, Coleridge has this to say in *Theory of Life*:

> But a physical atom is ens fictitum, which may be made subservient, as ciphers are in arithmetic, to the purposes of hypothetical construction per regulum falsi; but transferred to Nature, it is in the strictest sense an absurd quantity; for extension, and consequently divisibility, or multeity (for space CANNOT be divided) is the indispensable condition, under which alone anything can appear to us or even be thought of as a thing. (45)

In idea and expression, the above passage is strikingly similar to what Leibniz presented in the correspondence with Clarke: that absolute space, time, and the atoms as proposed by Newton are an "impossible fiction." This passage clearly denies both the indivisible, nonmoving matter and the divisibility of space necessary for the absolute space and time needed in Newtonian mechanics. Coleridge develops these ideas of space, especially in relation to time, quite extensively in his *Marginalia, Shorter Works and Fragments, Logic, Letters,* and *Notebooks*. One striking example of his break with Newtonian ideas of absolute space and time appears in a notebook entry in January 1804:

> "Coarctation" not a bad phrase for that narrowing in of breadth on both sides . . . of the Coarctation of Time into Space my own image . . . by space I meant co-existent multitude—in this instance of Images of my own self. (*Notebooks* 1:1823)

In this entry are several key elements in which space and time exhibit relativistic traits. First the word *coarctation* means to compress tightly or narrowly, as Coburn points out in her accompanying notes to the *Notebooks* (1:1823n). Critically, Coleridge describes not only a compression of time *and* space but a coarctation of time *into* space. The effect is intensified in that the self is presented as a multitude across this block of fused space-time. The context of the entry is that Coleridge has roused from a dream. The dream then becomes an imaginative space, a framework in which the self has access across space-time. Furthermore, this idea at the time of the entry during January 1804 is a recurring rumination for Coleridge. In letter number 513 to Southey a few months prior, Coleridge says "there is a state of mind, wholly unnoticed, as far as I know, by any Physical or Metaphysical writer hitherto . . . it is a transmutation of the succession of Time into the juxtaposition of Space" (974). This letter speaks also of the sensing or intuiting of a fused space-time within the imaginative mental framework of delirium brought on by illness and dreams.

But what does this mean? And why does Coleridge have these thoughts in conjunction with visual images of himself being called into creation of this space-time? Here in the 1804 notebook entry a multitude of self-events emerge from a fusion of space and time. Remember that for Coleridge, as with Leibniz, space is not divisible; therefore, time as it is merged with space is also indivisible. His is a fairly good layman's description of the space-time continuum—a block universe in which all of time and space are coexistent. Now is a relative term dependent upon relative measurement of motion or "slicing" up the block of space and time. When taken to its logical end, such a view denies presentism and calls into question movement and change, or the progression of time. Coleridge is also correct to claim that other writers at that time had yet to assert this philosophic proposition directly. Leibniz expresses the relational aspects of space and time, but the block universe is a further implication of this, as Einstein was to reveal in the twentieth century.

Between 1794 and 1804, Coleridge developed ideas and solidified a philosophic theory that allowed for a relativistic description of space, time, and matter. His poetic production during this period further reveals this development. As was pointed out in the beginning of this chapter, the poem "Coeli Enarant" from the notebooks provides a blatant example. The relativistic description in that image is of time, "Summer's Eve," creating the physical "web, / a Space" (8–9). Just as important as the description of this new space-time are the implications of space-time for the human experience in such a relativistic universe. The poetic imagination is dependent upon the poet's intellectual worldview. As Snyder points out, "the poet not only seizes upon those elements of a given world-view that fulfill certain conditions posited by the very nature of the aesthetic experience, but, where the given theory falls short, he supplements it by something not at the time intellectually definable, though clear to his poet's intuition" (616). Coleridge's intellectual worldview is formed under the pressure of the debate between Leibniz and Newton as to the nature of time, space, and matter. Coleridge clearly adopts a worldview reminiscent of Leibniz. At the same time, his poetic imagination intuits a more fully relativistic universe available to the self in dream or mental experiments that will not be "intellectually definable" for another hundred years.

Just as important as the intellectual description of space-time are the implications for the effect of the human experience of an intuited relativistic universe. This play between the sensory confirmation of a Newtonian system and the intellectual acceptance of a relativistic Leibnizian system is at the core of Coleridge's lifelong project to develop a theoretical philosophy of everything. The attempt to use the mental-imaginative space to create expression of the Leibnizian relativistic universe also serves as a useful lens through which to view Coleridge's poetry, especially the poetry produced between the years 1794 and 1804, the apex of Coleridge's poetic achievement.

During this time Coleridge wrote several famous examples of what M. H. Abrams was later to call the "Greater Romantic Lyric" (530). This form of Romantic verse emerges in Coleridge's work concurrently with his development of a worldview influenced by relativistic natural philosophy. It is necessary to examine what influence this relativistic natural philosophy may have on this poetic form for Coleridge. In his now classic reading of "This Lime Tree Bower My Prison," Abrams emphasizes that these poems use the Renaissance idea of *liber creaturum* and its analogic correspondence of the book in nature to "evoke in the reader the shock of delightful discovery" (536). The greater romantic lyric begins with the narrator in a local, even homely environment. From this static physical space, the narrator begins a psychological journey outward, occupying a mental space that may be either a real space known to the narrator or even an exotic or fantastical space. The narrator then exists concurrently in the physical local space and the mental-imaginative space. In the mental space of the journey, the narrator confronts some thought, idea, or image from which he must turn; the alienated narrator then returns from the daydream space to the physical environs of the local and sensible. The mental journey of the narrator not only visits different spaces but often moves through various points in time past, present, and future. Coleridge's best example of the temporal movement in the mental space of the greater romantic lyric form is probably "Frost at Midnight." In this poem, Coleridge imagines several self-events (as in the image of a multitude of selves in the dream about coarctation from his notebooks) of both the past and future, not unlike the dream states he identifies as the coarctation of space and time. Christopher Miller points out that in this identified verse structure "the speaker stations himself in space, wanders spatially and temporally through recollection or anticipation, and finally returns to the outer scene with a new clarity of understanding" (163). If we accept this premise of the structure of the poem and then view "This Lime Tree Bower My Prison" through the established lens of the debate between the material Newtonian system and the theoretical relativistic system of Leibniz, the form of the greater romantic lyric, as well as individual examples, takes on a much greater complexity regarding space, time, and the juncture of the human self.

"This Lime Tree Bower My Prison" is an early example of the greater romantic lyric in Coleridge's career. The first version occurs in 1797 in a letter to Robert Southey (*Collected*

Letters 1:333) and the poem undergoes revisions until the form is solidified canonically in *Poetical Works* in 1834. Although there may be dissent on exactly when Coleridge read Leibniz, there is reason to focus on this poem. As was established earlier, Coleridge's indirect contact with Leibnizian principles, at least, is certainly in play at that time. Additionally, the initial poem is significantly revised *after* Coleridge had definitely read Leibniz and developed his own relativistic philosophies. In "This Lime Tree Bower My Prison," the daydream journey of the narrator is meant to recreate the experience of an actual journey being made by Charles and company in the poem. Much depends in the poem on the events of the space of the daydream journey and the seemingly simultaneous events of the physical space of the narrator at rest beneath the lime tree. For Coleridge the use of the daydream reverie is a narrative mechanism to recreate or induce in the reader the dream state in which he first perceived the possibility of a mental state that "is a transmutation of the succession of Time into the juxtaposition of Space" (2:974). This narrative mechanism corresponds rather well to Einstein's ideas of the psychological origin of the concept of time:

> This concept is undoubtedly associated with the fact of "calling to mind," as well as with the differentiation between sense experiences and the recognition of these. Of itself it is doubtful whether the differentiation between sense experience and the recollection (or re-presentation) is something psychologically given to us. Everyone has experienced that he has been in doubt whether he has actually experienced something with his senses or has simply dreamt about it. (*Relativity* 139)

The greater romantic lyric form puts both the sensible experience and the dream state side by side. The form calls out the psychological slippage between different experiences of space and time. The narrator begins the poem after his friend's departure. The addressee of the poem Charles and the others in his company are in motion relative to the narrator. The time period established in the poem seems to be between midday and sunset, as measured by two different experiences (a physical, sensible experience and a mental, daydream experience) or temporal-spatial frameworks. The poem thus begins with a spatial-temporal relativity. Space and time, as concepts in the poem, can be read as dependent upon relative relationship of the two different frameworks or experiences, as in a Leibnizian description of the universe rather than as absolute, as described by a Newtonian physics.

As Christopher Miller points out in his analysis of the poem, the events beneath the tree and the events of the daydream journey are imagined to be parallel simultaneous events. Simultaneity and parallelism of events in physics are framework dependent—meaning they are dependent on who is measuring time. The narrator has access to various self-events in relationship to each other. The reader must recreate the relational frameworks while being one step further removed. This *imagined* simultaneity is at the crux of the matter in a description of time and space in a more Leibnizian relative space. Therefore, in such relative frameworks, each framework in relative motion will slice up time and space differently. Charles on his actual physical journey, the narrator static beneath the tree in a physical sensible space, and the narrator moving through the journey of the daydream space will each have a different measurement of time. This means that from one framework an event may be present when from another it may already be past or still awaiting its future. Whether the event is in the past or future relative to the viewer, it is already *there* in a real sense. "This Lime Tree Bower My Prison" recreates in words an indivisible space-time and in so doing shows the impossibility of true simultaneity through its use of images, tense shifts, and the linguistic tension in fluctuations between the terms *now* and *still.*

In a relative space of motion, measurement is intensely important, so the choices of movement and motion as images are key to understanding Coleridge's depiction of time and space in the poem. The image of the sun—that most sure and ancient device for human measurement of time—hangs over the poem. It hangs over both the narrator and addressee in the poem. If time and space were absolute, as they would be in a Newtonian universe, the image of the sun should be a marker by which both frameworks would measure identically and which would synchronize simultaneity or parallel events in time and space. This poem would depict a human experience of movement through a three-dimensional space. Time and space in such images could be sliced into events that happen at exactly the same moments; there would be true simultaneity, as in a Newtonian worldview. Yet, the narrator uses language of qualification whenever making references to the events in the addressee's and narrator's spatial-temporal frameworks. This uncertainty of framework begins as soon as the addressee Charles sets out in motion relative to the narrator, who is confined in the garden due to his injury. Lines seven through eleven read:

> On Springy heath, along the hilltop edge
> Wander in gladness, and wind down perchance,
> To that still roaring dell, o'erwooded, narrow deep.
> And only speckled by the midday sun.

The revisions to the poem include the last quoted line, which establishes the point of departure as "midday." This change allows for a finer distinction to be made between the space-time of the narrator beneath the tree, the space-time of the narrator in the dreamscape, and the space-time of Charles on his actual walk in the poem. The narrator knows the path and destination of the traveling group and has made the trip frequently himself, so if time were absolute and reliable, and if he knew the destination and rate of going, he should be sure of location and simultaneity. Further, he has an ostensibly exact time for measurement in "midday." Yet this event is designated as "perchance." The event is "perchance" not because there is doubt that it will occur or has occurred but because the narrator cannot be sure of simultaneity. Simultaneity is only possible in Newtonian philosophy, not in a Leibnizian one. This same problem recurs in lines twenty through twenty-five, where—or *when*—the events are qualified with "perhaps" in line twenty-four. This "perhaps" is also a later addition, written after Coleridge had solidified his ideas of the relativistic dream state. The marker of the setting sun is mentioned again only a few lines later. In a system in which time could be divided into neat slices of the present, no such qualification should be needed.

As established earlier through the examination of Coleridge's philosophy and scientific explorations, Coleridge sees space as indivisible and, because he sees time as fused with space, for him the whole of time must be indivisible. If that is so, all events exist together. One of the consequences of coexistent events in a block of time is the problem of having language to express such a vision or system. After all, the Newtonian explanation of time and space as absolute held sway for such a long period of time because it seemed to conform to human experience so well. A relativistic description of time and space is counterintuitive. Language choices are therefore limited when expressing ideas that are incompatible with human sensory experience. The English language divides time into past, present, and future, as though one self moves forward through a linear time. Coleridge instead must try to mimic the multitude of self-events and non-simultaneity intuited in the dream-state coarctation with language that reflects a Newtonian sensory description of moving forward through space-time. One of the most curious things about the language choices in "This Lime Tree Bower My Prison" is the shifting of tenses in the narrator's tale.

In line one, the narrator begins squarely in the present with "they are gone" and "I must remain." Although both verbs are present tense, each as an indicator of extension implies carrying the present state into the future. The narrative journey out to the addressee wanders through tenses and reference frames fairly indiscriminately. The narrator beneath the tree first imagines himself in a non-occurring timeline:

> I have lost
> Beauties and Feelings, such as would have been
> Sweet to my remembrance, even when age
> Had dimmed mine eyes to blindness. (2–5)

He attributes an actual past "I have lost" with a conditional one "as would have been" juxtaposed alongside a conditional future "when age had dimmed my eyes to blindness." It may be asserted that this mere trick of language is possible because the events have no real-world correspondents in the poem. However, events that do have real-world correspondents, at least in the world of the poem, also show such time anomalies. The narrator goes on to state:

> They meanwhile
> Friends, whom I never more may see again,
> On springy heath along the hilltop edge
> Wander in gladness. (5–8)

"Meanwhile" is a seeming marker of simultaneous present. With what exactly are the friends simultaneous? Is it the non-occurring imagined space of the future self from the previous line? Even if the simultaneous event is the musing itself of the narrator, to what does it connect? The musing would connect to the friends' wandering, which has already been qualified by "perchance"! Furthermore, "friends" and "wander" are intersected with a conditional future "I never more may meet." This pattern of tense shifting and intersecting occurs throughout the poem. It sometimes accompanies a shift between the narrator's mental space and the space he imagines the addressee inhabits physically on his walk. This shifting also occurs, however, within one seemingly inert frame—that of the narrator at rest in the lime tree bower. Miller points out that one such shift occurs near the end of the poem with the use of "the habitual present—a tense that encompasses both what is past and what is yet to come, and implicitly joins the dispositions of both poet and addressee" (65). This linguistic representation of a spreading tense makes reference to all positions in time because two different spatial-temporal frameworks are available at once.

Coleridge's use of language to capture the co-presence of space and time seems to support Snyder's claim that the aesthetic experience will call out what is at the time theoretically intellectually indefinable. To further express this co-presence of space and time implied in the usage of tense, Coleridge uses the terms *still* and *now to* great effect. Consider the following lines, 52–60:

> And that walnut tree
> Was richly ting'd, and a deep radiance lay
> Full on ancient Ivy which usurps
> Those fronting elms, and now, with blackest mass
> Makes their dark branches gleam a lighter hue
> Through the late twilight: and though now the Bat
> Wheels silent by, and not a Swallow twitters
> Yet still the solitary humble Bee
> Sings in the bean flower! Henceforth I shall know...

Miller points out the importance of the word "still" and its etymological shift from the Old English "motionless" to the "adverbial sense of persistence or continuation," the change that reflects the translation of the spatial (an unmoving thing) into the temporal (a thing or state that stays constant through time) and the static into the inertial (65). Stasis in terms of physics is a classical to medieval concept, and the inertial is a Newtonian concept of space. I believe that Coleridge moves beyond his Newtonian "still" by juxtaposing or coarctating it with a rapid succession of "nows." He first moves from the past of "was richly ting'd" and a "radiance lay" to the present of "usurps." The connecting spatial point for this tense shift is the enduring object of the "ancient ivy." Here, time appears to condense and be sliced in smaller narrower portions one after the other with "and now with blackest mass" and then "and though now the Bat / Wheels silent by."

The second instance of "now" in description of the motion of the bat is significant as it is a later addition not present in the original letter version of the poem that intensifies the seeming slice of time. Yet the next line returns to the "Yet still the solitary humble Bee sings." This "still" is ambiguous indeed. The bee may be motionless in a kind of "stasis." It may be that the bee persists or continues. Or it may be that the constant motion of the bee appears as stasis. It is impossible to pin down grammatically. These "nows" seem to represent measurable motion and change between seeming past and immediate present. However, with the return to "still," each "now" may or may not have occurred simultaneously with the song of the bee. It is not clear that each "now" has slid to a past. In some sense each "now" is still ongoing and present. Furthermore, Coleridge projects into that future with "henceforth," indicating "from now on," but from which "now" does the narrator proceed? The last of them? All of them? Each "now" is in some sense eternally available. The moments of time only seem to be captured, to be sliced off and isolated as a succession.

This effect recurs at the end of the poem with the rook silhouetted against the sun:

> I blest it! Deeming its black wing
> (now a dim speck, now vanishing in light)
> Had crossed the mighty Orbs dilated glory
> While thou stoodst gazing; or when all was still
> Flew creaking o'er thy head (71–75)

Note that the "now" of line 72 is a later addition as well, one that does not occur in the 1797 letter version. Here "nows" again seem to measure moments in succession—small slices of time—yet this motion is relative between two frameworks in space-time of the narrator and the addressee. That rook against the sun is motion against measure, as imagined from two different frameworks. These "nows" are even given two possible events as parallel "while thou stoodst" and "all was still." They are connected by an "or," an interesting indication that could mean that either "now" could correspond to either event. Either event refers to the addressee Charles, so our narrator imagines a dream space-time in which there is not only a multitude of self-events but the possibility that all selves are multitudinous.

The implication of events or "nows" being available to past, present, and future depending on the frame of the measurer moves well beyond the Newtonian idea of absolute space and time—it becomes relativistic. And the relativistic is clearly attributable to Leibniz, and only Leibniz, until the twentieth century. As Coleridge writes in the *Notebooks*, "It surely is not impossible that to some infinitely superior being the whole universe may be one plain—the distance between planet and planet only the pores that exist in any grain of sand" (1:93). Scholars have interpreted this difficult passage differently. Coburn traces this passage to roots in Newton in her notes on the text. This attribution is accurate as far as it goes with regard to the compression of matter. However, this compression of matter in a Newtonian sense is complicated by Coleridge's views of the indivisibility of time and space. In such an explanation of the universe, in a planar existence in which space (and therefore time) is present in one block in a coexistent manner, there are serious implications for our existence. As Einstein was to point out more than one hundred years later in his book *Relativity*:

> Since there exist in this four-dimensional structure no longer any slices which represent "now" objectively, the concepts of happening and becoming are indeed not completely suspended, but yet complicated. It appears therefore more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the evolution of a three dimensional existence. (150)

Einstein's carefully chosen words allude to a universe with all of space and time robustly available depending on the viewing framework. The implication of such a block of space-time is astonishing. Movement and change or, as he says, "happening and becoming" simply may not be as they seem. Such a four-dimensional existence is in many ways a framework not unlike the controlling metaphor or framework controlling Coleridge's poem. It is essentially a prison in which change and becoming are a product of our own mental narrative.

NOTES

1. See Werkmeister and Wordsworth for further discussion of possible paths of philosophical influence.

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Jakob Friedrich Fries on Inference Types in the Natural Sciences

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Will man Kants Programm heute noch als eine Möglichkeit methodisch reflektierter und empirisch interessierter Wissenschaftstheorie begreifen, die den Problemen des Induktivismus wie der traditionellen Metaphysik entgeht, muß man zuallererst seinen absoluten Begründungsanspruch aufgeben und nach Möglichkeiten suchen, sein Programm in wissenschaftsadäquater Weise weiterzuentwickeln. Ansätze hierzu sind in der ersten Hälfte des 19. Jahrhunderts vor allem bei William Whewell und Jakob Friedrich Fries gegeben.[1]

If we want to understand Kant's program today as the possibility of a methodologically reflected and empirically interested theory of science, that does not have to take into account the problems of inductive science and traditional metaphysics, we have to give up his demand for absolute proof and look for alternatives that develop his program according to scientific developments. This new approach can be found in the first half of the nineteenth century, especially in William Whewell's and Jakob Friedrich Fries' work.

As a philosopher, Fries was always controversial. He was and still is accused of merging transcendental and empirical questions in his anthropological critique of reason.[2] Indeed, Fries's defenders argue that his critics have never been able to articulate their objections clearly: not a single proposition that had been set up in the name of transcendental philosophy as unshakably, *a priori* valid persisted. The most prominent example is the law of causality. Fries presumably recognized that knowledge had to be *a priori* infallible, but not its philosophical explication, which can be subject to historical change (Hermann 72–73). But the question arises, how can transcendental deduction in Fries's sense be differentiated from a basic analytical "manifestation" of principles that are presupposed in the factual use of language? In other words, how can transcendental knowledge be separated from reality if *a priori* knowledge is revisable? (Dubislav 34, 37). Aligning himself with Jacobi's movement of "counter-Enlightenment,"[3] Fries rejects this fundamental discussion and argues that all knowledge ultimately depends on unproven assumptions. As Jacobi would say, it depends upon a system of "belief."[4]

In the spectrum of the authors included in this volume, Fries is of interest, not primarily as a transcendental philosopher but rather as a former philosopher of science who had provided a definition of physics as a science.[5] The question, "Physics: Science or Art?" can indeed be clearly answered for Fries, particularly in his separation of the strict scientific knowledge from emotional, religious, and aesthetic perspectives of the world. It is true, Fries admits, that for physics as pure science, the question of the meaning of the world remains unanswered. Yet these findings only encourage him to make a strict differentiation between science on one hand, and emotion, taste, and faith on the other hand ("einer strengen Unterscheidung zwischen Wissenschaft einerseits und Gefühl, Geschmack, Glaube andererseits" [Bonsiepen 427]).

Fries's achievements in the scientific theory of natural philosophy (*Naturphilosophie*) have been noticed—even if only marginally—for a considerable time now. Popper acknowledged him as the discoverer of the so-called basis problem:[6] if scientific knowledge consists of the reduction of empirical facts to the hypotheses that explain them, then science is only possible if it is based on the connection of theory and experience. The basis of scientific knowledge cannot be a "pre-established" (*keine gegebene*) reality; rather, it presupposes a connection between theory and empirical information. Fries explicitly rejects the idea that one could derive natural laws that explain phenomena through abstraction of the observation of these phenomena: "All observation can only render approximate results; we can never deduce with clear distinction a natural law from mathematical calculation" ("Ueberhaupt alle Beobachtung gibt nur annäherungsweise Resultate; wir können aus der Beobachtung nie mit völliger Schärfe der mathematischen Bestimmung ein Naturgesetz herleiten" [MN 22]).[7] The object of an observation is always a unique process or a specific phenomenon from which unlimited characteristics can be determined. What kind of characteristics of an object can be determined by observation is inevitably subject to chance. An object is generally perceived as a phenomenon and not as a thing: for Fries, observation is certainly a practiced and qualified perception, and therefore not absolutely exact. Conversely, laws are universal hypotheses that do not determine an object completely or comprehensively but represent the quintessence of an object from a point of view that can at best be approximate. Therefore, it is equally impossible to derive phenomena from laws; instead, hypotheses must be seen as projections to be tested by phenomena. Fries identified, long before Popper, falsifiability as a criterion of meaning of scientific hypotheses: "one should never set up any presupposition that can be refuted by experience" ("man solle keine Voraussetzung machen, die nicht bestimmt von der Erfahrung widerlegt werden könne" [MN 21]).

The first impression of Fries's *Naturphilosophie* suggests that it is nothing other than a rewriting of Kant's *Naturphilosophie*, inspired by both philosophy and science. Fries's *Mathematische Naturphilosophie* (1822) already explicitly pointed in its structure to Kant's *Metaphysische Anfangsgründe der Naturwissenschaft*, but it can hardly be seen as the Kantian corrective and expansion of the transcendental philosophical basis of Newtonian physics that Fries had in mind.[8] Whoever seriously promotes this point of view would have to consider that, for example, the causal law must be seen as constitutive for every possible experience. It is true: Fries did render a methodological definition of the concept *Naturwissenschaft* (natural science) that counteracts some abbreviated versions from much later periods. The scientific and philosophical value of a mathematical *Naturphilosophie*, as the following argument will show, is a methodological value. It fits seamlessly into Fries's program of logic as a methodological doctrine in which the relation of mathematical construction and empirical intuition (*Anschauung*)[9] helps to clarify and counteract an abbreviated reductionist understanding of natural science. In contrast to Fries's distinct separation of feeling and reflection on the one side and science on the other, it becomes evident that, throughout his work, Fries allows connections between aesthetic and scientific conceptions of the world; indeed, he even points to the possibility of such an intersection.

Philosophy as a Methodology for the Natural Sciences

From the perspective of scientific theory, one of the most interesting aspects of mathematical *Naturphilosophie* is that it does not limit the explanations of empirical phenomena to mathematical theories but recognizes other forms of interconnection that partly evolve out of scientific research and aesthetics. Such a systematic analysis of types of inference that are applied to the merging of speculation and experience essentially facilitates the explication of the concept of natural science, as opposed to a study of nature exclusively defined through observation, description, and classification. On the one hand, this leaves Kant's constraint of the concept of science to quantification and reductive explanation behind, while on the other hand it clearly distinguishes between everyday, scientific and aesthetic conceptions of the world. The following analysis will highlight the important role that the different types of inference played in Fries's philosophy of science in order to interpret the background of mathematical *Naturphilosophie* as methodology in natural science. The goal of investigation is a critique of the Newtonian proof of general gravity. The word *critique* is to be understood in the bifurcated meaning that is typical of critical transcendental philosophy. On the one hand, it concerns itself with a critique of Newton's dogmatic methodological concepts that encourages the widely accepted rejection of his "proofs" in modern scientific theories. At the same time, it supports clarification of the arguments that Newton applied and, in the sense of a critical reconstruction, whose argumentative power he defined.

Fries's program depends on scientific concepts and scientific criteria for meaning, which will be briefly outlined here. The most general premise of the program is the presumption of a unified science. All human science (*menschliche Wissenschaft*) is for Fries natural science (*Naturwissenschaft* [MN 1]) that subsumes objects or experiences gained through empirical perception into laws. To this, he adds, "all scientific knowledge is concerned with this classification of the phenomena of our sensory perceptions into their laws" ("daß alle unsere wissenschaftliche Erkenntniß diese Unterordnung der Erscheinungen in der Sinnenwelt unter ihre Gesetze betreffe" [MN 1]). More certain and slightly more interesting is the presupposition that, according to Fries, reference to objects of empirical perception is necessary. It is a categorical mistake, or a "mistake of a lazy reason" (*Fehler des trägen Verstandes* [MN 1]), that everything that belongs to perception is derived from concepts. This understanding has far-reaching implications in regard to the question of what can actually be a proof in natural science. It is true that phenomena cannot be derived from theories; an alignment between deductively confirmed general empirical premises and general *a priori* premises of a mathematical theory cannot constitute a deductive relation based on these presuppositions. An important step in the process of examining scientific theories in critical rationalism—the derivation of basic premises from theory—is inadmissible in Fries's philosophy of science. From this emerges, as we shall see, a fundamental difference in the appreciation of Newton's theory of gravity.

Fries's philosophy of science is further determined by an antiformalistic understanding of mathematics. As Fries sees it, this is different from logic insofar as it concerns the philosophical logic of the law of valid deduction, which he understands, following Kant's footsteps, as a formal canon of reason; in contrast, mathematics finds a componential meaning in a pure doctrine of motion (phoronomy). The concept of motion (*Bewegung*) is completely determined by mathematics.[10] That means that all natural phenomena that can be traced back to motion can be explained exclusively using mathematical methods.

The object of a mathematical *Naturphilosophie* is therefore not the general characteristics of bodies and relations between bodies but what is knowable *a priori*, "that which is assigned to all matter according to it's *a priori* determined laws of mathematical perception" ("welche aller Materie nach den *a* *priori* bestimmten Gesetzen der mathematischen Anschauung zukommen müssen" [MN 23]). From this point of view, mathematical *Naturphilosophie* appears first and foremost as an abstract structural scientific concept:

> Die Erkenntniß der Wesen nach ihren sinnlichen Qualitäten, nach Farbe, Ton, Duft, Geschmack, u.s.w. so wie die Erkenntniß des geistigen Lebens erhält nur vermittelst jener Erkenntniß von Gestalt und Bewegung ihre Raum- und Zeit-, ihre Zahl- und Gradbestimmungen, ihre Unterordnung unter Gesetz und Regel. (MN 3)
>
> The knowledge of phenomena derived from their physiological qualities, color, sound, smell, taste, etc. and the knowledge of mental processes only produce knowledge about space, time, number and degree, their classification under laws and rules, if it is based on knowledge about form and motion.

In contrast, Fries declares the understanding of sensual qualities as expressly relevant for a scientific worldview. A complete reduction of phenomena to mathematical *Naturphilosophie* has never been intended. The reflection that emanates from the particular object of sensual perception, which discloses a multitude of predicates that can be allocated to it, and which Baumgarten and Kant assign to aesthetics (*Ästhetik*), is for Fries an integral part of science. One of the most interesting aspects of Fries's concept of science is that he never completely distinguishes between scientific and aesthetic concepts of the world. In a literal sense, a scientific (mathematical) understanding of phenomena needs to be supplemented with concepts that do not have a reference to empirical perception—as, for example, unity or force. These concepts are determined as regulative ideas that must supplement the universality of a law by comparing and combining several phenomena to a particular unity. These achievements of reflective judgment belong to the aesthetic concept of the world and "gain complete meaning in the aesthetic judgment among ideas" ("erhalten ihre vollständige Bedeutung in der ästhetischen Beurteilung unter Ideen" [MN 3]).

But how, according to Fries, can such differentiated procedures, like mathematical theories that are constructed as deductive axiomatic systems and aesthetic reflections that belong rather to the reception of the beautiful and the sublime in art and nature, be part of a unified science? An answer to this question is to be sought in the extensive, applied method of logic and doctrine, that Fries adds as the second part of "Logic" (*Logik*) to his doctrine of the forms of thought, and which he—in contrast to the marginal treatment of this theme found in Kant—strongly expands.[11] Here, the decisive point of view is that Fries's different methodical tasks are distinguished from each other and bound to different inference types. For the axiomatic presentation of a science in its pure—that is, conceptual and non-empirical—deductive logic is responsible; it subsequently leads to the subordination of empirical phenomena. In the sense of traditional logic, Fries relies upon Aristotle's syllogisms, which he understands as a logical and truthful inference scheme of concepts that can be organized according to higher characteristics and is determined by certain componential qualities. Leaving aside the fact that this conception of logical deduction according to contemporary understanding is too special for us today, the concept of inference is nevertheless unproblematic. For Fries, a logical deduction is attributable to an implicative declaration that states that the truth of premises is adequate to the truth of the conclusion.

It is the case that empirical findings can be represented in science from the premises of a theory as conclusions, and that these conclusions can never compellingly and, as a rule (which we shall see), never exactly correlate. The empirical statements are generalizations from observations that for a (mathematical) speculative theory can provide heuristic points of view but not a logical basis. According to Fries, the confusion of genesis and validity had generated especially in the empirical tradition "a false empirical theory of inductions" ("eine falsche empirische Theorie der Inductionen" [MN 614]). This theory is based on a methodical leap from that which previous experience had proven universal to that which is grounded on whatever the case had been (or what could occur next). But also the rationalist idea to determine induction as probabilistic relation between a sum of known experiences and a sum of still unknown experiences according to the measure of an experiment of chance is—according to Fries—flawed on the basis of categorical reasons: inductive conclusions, be they prognoses or generalizations, must be based on hypotheses of laws. Not only does a specific universal hypothesis that could be refuted through counter examples have to be justified—so does the fundamental idea that empirical laws are "true" (*echt*) and immutable. Hume had already demonstrated that there is no logical justification for the connection of arbitrary factual truths such as "Bread has nourished me according to my experience and therefore, it will always nourish me" ("Brot hat mich in der bisherigen Erfahrung ernährt, deshalb wird es mich immer ernähren") or "The sun has always risen according to my experience and that's why he will always rise" ("Die Sonne ist in meiner bisherigen Erfahrung immer aufgegangen, deshalb wird sie auch morgen aufgehen"). In contrast to a number of later authors—among them Laplace—Fries now adds that these basic assumptions cannot be probabilistically justified because they are not applicable to any experiment of chance. Experience is dependent upon universal connections of facts that do not allow any contrary examples. The criticized authors "wrongly believe that they can apply independently the method through induction for their calculations and mistake them partly for the mathematical conclusion of probability" ("meinen fälschlich die Beweisart durch Inductionen auf eine unabhängige Weise für sich anwenden zu können und verwechselten sie zum Theil mit dem mathematischen Wahrscheinlichkeitsschluß" [MN 614]).

In reality, scientific inductive methods now combine, according to Fries's formidable analysis, a speculative (mathematical) theory that supplies explanatory hypotheses with an empirical theory that contains universal empirical statements. In speculation, deductive conclusions are the result; in empirical theory, observations and experimental demonstrations are decisive. Scientific explanation is a conjunction of both—under the premises of unity, constancy, and efficiency that secure a consistent connection of the same effects with the same causes in nature. These supreme premises are maxims that can be taken as universally valid and cannot fail in experience because contrary examples do not exist in experience. The question of how mathematical theory—for example, motion—can be connected with empirical phenomena—for example, the motion of the planetary spheres—doesn't fall to mathematical theory but is instead guaranteed through plausible deductions. We can agree with Fries and consider these deductions plausible because they support themselves with the knowledge that cannot be justified *a priori* (that is not necessarily true). The course of nature must not be constant; we presume that this is the case in everyday as well as in scientific experience. In logic and generally in speculative theory, an argument of this kind does not rely on a formally valid scheme but on an argumentative scheme. In the interest of a reconstruction of Fries's distinct inference types, we could characterize this as "materially conclusive" (*material schlüssig*). If a formal deductive scheme conveys the truth of the premise to the conclusion so that the conclusion is true under the presupposition that all premises are true (in other words, the scheme contains truth but is not proof of the truth of the conclusion), then the material deductive argument of the interpretation depends on the applied signs. Let us consider the proposition "Cajus is mortal" as derivative of the proposition "Cajus is a man" but not as the basis of the logical relation between both propositions but as the basis of the meaning of the constants "man" and "mortal" (traditional logic, supported by the subordination of concepts, conceals tendentiously the meaning of the difference between formal and material deduction). It follows that the plausible argument does not support the truth and is not formally valid, although it supports the conclusion; in some cases, it even proves these—for example, when from the certain indication that Sarah has milk it is deduced that Sarah will have a child. In analogy, our belief that unity, constancy, and efficiency prevail in nature makes plausible the presupposition that with relatively little speculative theory we can confidently explain a great number of empirical phenomena. Fries assigns to his maxims of research the function of justification; he also assigns them a heuristic function insofar as they facilitate analogous deductions—for instance, the conveyance of the laws of gravity to the doctrine of electricity.

Scientific and Aesthetic Argumentation

Despite its impressiveness, does this outline of a research method not depend upon "aesthetic ideas" in the sense of reflective judgment? It is helpful here to differentiate between the problem of a connection between speculation and experience in science and, on the other hand, a presentation of scientific theories through an appropriate language of signs. In the linguistic-philosophical part of applied logic, Fries expressly acknowledges Leibniz's demand for a *characteristica universalis* as an ideal language of science, but—we might add—not for all sciences: only for those that can represent themselves schematically. This is in a unique way the case in arithmetic. In contrast, philosophy does not have at its disposal the possibility of a schematized and solely symbolic construction in which nothing depends on the significance of the signs. On the contrary, philosophy is reliant on conceptual analysis, which leads to straightforward logical ideas without empirical meaning: "In contrast, true philosophical concepts cannot be schematized in a straightforward way; therefore, philosophy only works with signs that are not free characters but symbols" ("Hingegen ächt philosophische Begriffe sind für sich mit gar keiner Klarheit zu schematisiren, die Philosophie kann daher keine andre eigne Zeichen besitzen als bildliche, die nicht freye Charactere, sondern nur Gleichnisse sind" [SdL § 456]). Because philosophy does not rely upon clear and distinct signs for the denotation of thoughts, it remains dependent upon the hypotyposis (*Veranschaulichung*) of thoughts using particular examples. Hypotypose is the representation of an idea using an object of empirical perception. This representation is, as Fries says, very much in the tradition of Baumgarten and Kant, an aesthetic idea or *perceptio praegnans* that evokes much reflection without eventually arriving at a concept. As a result, it is important to note that natural science, whenever it has to rely on "philosophical probability" as a leading maxim of research—that is, on philosophical ideas (this is the case with all inductive methods that combine speculation and experience)—it is also dependent in its representation on the "rhetorical probability" on a successful description of ideas. This insight compels Fries to adopt an important modification of Kantian aesthetics, where aesthetic judgments can only produce contemplative functions and not cognitive values. This change accompanies a rehabilitation of the rhetorical enthymemes that, according to Fries, combines a topical proof derived from at least one maxim with the description of an idea in the conclusion. We are thus able to derive from the fact that Dionysius demands bodyguards the fact that Dionysius seeks tyranny, since it is typical for tyrants in an aesthetic sense to have private bodyguards; the fact that Dionysius demands this is cause for reflection.

In summary, the following types of argument can be identified in Fries's texts:

a) Empirical, metaphysical, and transcendental deduction in philosophy, which justify categories

b) Logical deduction within axiomatic systems

c) Empirical demonstration through observation and experiment

d) Mathematical probability calculus for the average consideration of mass phenomena (e.g., observation dates with aberrations)

e) Deductions of philosophical probability in inductive methods

f) Deductions of rhetorical probability for arguments from representation

Maximal Proximity to a Constitutive Theory: Rational Mechanics

When mathematics alone is sufficient to constitute a phenomenon theoretically (to construe from its conditions of antecedence), Fries speaks of a "constitutive theory" (*konstitutive Theorie* [MN 11; SdL §§ 127–29]). Wherever empirical phenomena must be compared and experimentally placed under hypothetical laws (because they cannot be construed mathematically), he speaks of a "regulative theory" (*regulative Theorie*). It is fundamentally important that constitutive theories in a strict sense do no exist for Fries in any available study of nature: he argues that even a theory that is closest to this concept—namely, Newton's mechanics and its application to the motion of the planets—remains only an approximation to a constitutive theory and not its implementation.[12] This is also true to a greater degree for the theory of sound, light, and heat as well as electricity and electromagnetism. Fries is familiar with all of these theories in the natural sciences, which date back to the early nineteenth century, are concerned with approaches to constitutive theories, and mostly depend on experimental methods. To distinguish this terminology, we will use in the following analysis the term "approximate constitutive theories" (*annähernd konstitutive Theorien*).

Fries did not simply categorize natural scientific theories into *constitutive* and *regulative* but—knowing well that this had not yet been achieved factually and could not be achieved partially because of categorical reasons—formulated the maxim to arrive at constitutive theories whenever possible. This is especially true for systems of classification, as they were known in botany and zoology, where they were derived through comparison and combination. The basis of these systems consists of empirical methods of observation and description. They concentrate on individuals and attempt to classify particularities within general criteria of evaluation. The particular that can be more or less observed through modes of perception cannot be eliminated; according to Fries, it is also not possible to reduce individual appearances to a mass of phenomena. Thus, the combined methods distinguish themselves in terms of experimental methods; the latter are set up for the methodically certain, repeated production of a phenomenon and are suitable for quantitative examination. According to Fries, all study of nature that claims to be natural science has to follow two practical rules: On the one hand, it has to aim at reaching normative maxims that provide maximum unification of phenomena under constitutive theories. On the other hand, it has to accept the premise and pay attention to the essential limits of the constitutiveness of phenomena: it has to take notice of the peculiar law of regulative theories and not confuse the different empirical, speculative, and inductive methods of research. In his *Naturphilosophie*, Schelling had made this elementary categorical mistake and confused the combined methods of description of nature with mathematical methods of speculation (MN 3, 17).

If we take a closer look at Newton's theory of gravitation as an example of an "approximate constitutive theory" (*eine annähernd konstitutive Theorie*), it can be stated that besides the mathematics of motion, basic concepts such as space, matter, and forces that generate motion can be presupposed. Both Kant's and Fries's mathematical *Naturphilosophie* attempted in the interest of a constitutive theory of gravitation to justify their basic principles *a priori*. In every modern discussion of the theory of science, this method is only of historical interest, although the critical cogency of their opposition to Newton is acknowledged to some extent. Kant's concept of space as an idea of reason defines space as a structure of cognition and inverts Newton's notion of an absolute space in the sense of a transcendental revolution of cognitive powers.[13] Alternatively, Kant and Fries look upon gravity as a basic force that requires a justification prior to all experience. However, in the *General Scholium* at the end of the *Principia*, it is evident that Newton had already assumed that gravitation was not a fundamental force but only the basis for a mechanical explanation of motion in our solar system.

First, Newton makes it clear that gravitation cannot itself become an object of a mechanical explanation, a premise with which Kant and Fries both agree. If one wanted to explain gravitation mechanically with the pressure and collision of corpuscles, then the magnitude of gravity is dependent upon the magnitude of the surface of the body. In fact, it depends on the magnitude of the body as well as the distance from the center of gravitation (Cohen 64). The assumption that gravity, as Newton said, really exists cannot be proven with an empirical examination of mechanical theory. The question of the reality of gravitation and its cause is bracketed. Newton's scientific "style" is characterized by basic assumptions about reality as a whole; these are grounded in his alchemist studies and are not only suppressed but consciously hidden within the scientific part of his system—that is, in his rational mechanics (*Principia*, Books I and II), his theory of our solar system (*Principia*, Book III), and his theories of light and color (*Opticks*; Cohen 60). By and large, Newton assumes an alchemistic conception of the world wherein reflections on the relation of activity and passivity as well as the reactions of sulphur and similar substances provide the basis for analogical observations. Consequently (that is, for these areas), these ideas can transition into scientific theories that are constructed through mathematics and experimentation. These ideas—and Fries is directly following Jacobi here—that scientific knowledge is conditional upon non-revisable statements of belief that ought not to be mistaken for science ties almost seamlessly into Newton's philosophy of science; nevertheless, there is an important difference. Like Kant, Fries acknowledges transcendental arguments; as already shown, however, he understands them differently. The transcendental philosophical program of a mathematical *Naturphilosophie* consists of the distinction between constitutive *a priori* knowledge in natural science and unsubstantiated statements of belief. Fries asserts in the opening passage of the

Mathematische Naturphilosophie "that in human convictions science has to be distinguished from faith in eternal truth, although science is subordinate to faith" ("daß in den menschlichen Ueberzeugungen diese ganze Wissenschaft vom Glauben an die ewige Wahrheit getrennt bleiben müsse, obgleich sie sich dem Glauben unterordnet" [MN 1]).

If one looks at Newton's celebrated exposition in the *General Scholium*, then it is abundantly clear that not all statements of belief have the same status for him. He is concerned here with the problem that he cannot provide a sufficient basis for general gravitation and the assertion of its very existence is in a certain manner a statement of belief:

> I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy . . . And it is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain all the motions of the heavenly bodies and of our sea. (Newton, *Principia* 943)

Newton does not know the difference between a transcendental foundation and an assumption that is based in belief, which for both Kant and Fries was of such great importance. Belief in presuppositions of existence has an altogether different status than belief in nature as a divine creation, because, in the first case, the opposite of the presupposed is excluded through the assertion. Accordingly, for pragmatic or transcendental reasons it does not make sense to assert the effects of gravity and, at the same time, to deny the existence of gravity.

Kant and Fries's program of a philosophy of nature is much stronger and aims at a transcendental justification of basic concepts, not simply their "empirical deduction" (evidence of their factual utilization). In this respect, gravitation becomes a basic force constitutive of every aspect of nature. Fries positions himself close to Kant, but a more careful examination shows that he backs away from some of Kant's assumptions—with the intention of constituting further areas of the study of nature that were not possible with some of Kant's constricting suppositions.[14] He therefore opposes Kant's concept that for every mass a degree of penetrative force of attraction is necessary; however, a degree of repulsion, which shows itself at contact, is brought about arbitrarily (MN 621). This understanding would make the force of attraction the sole predicate that could be justified *a priori* and applied in synthetic principles of natural science: "the law of gravitation and the elastic fluid would be the only law that could be determined *a priori*; the rest remains in an unspecified contrast and indeterminable" ("das Gesetz der Gravitation und die elastische Flüssigkeit wären das einzige *a priori* Bestimmbare, alles andere bleibt in einem unklaren Gegensatz nur empirisch bestimmbar," MN 621). Against this, Fries asserts "that the degree of force cannot be quantified; only the expansion at contact between equal parts of a mass can have an effect; in contrast, every concept of moving force can be constructed mathematically and consequently *a priori*" ("daß sich der Grad keiner Kraft *a priori* ausmessen lasse und einzig die Ausdehnungskraft in der Berührung zwischen den gleichartigen Theilen jeder Masse wirken müsse, daß aber dagegen jeder Begriff von bewegender Kraft ein mathematischer und folglich *a priori* construirbarer sey"[MN 621]). On the one hand, Fries accepts more *a priori*–constructed concepts than Kant does; on the other hand, he does not consider the identity of heavy and inert masses as *a priori* certain. Therefore, one cannot know if everywhere in the universe the same masses exert upon each other the same degree of attraction.

The main purpose is the extension of mathematical *Naturphilosophie*. For example, Fries formulates a philosophical dynamism as a basic proposition: "All basic notions about the essence of matter and its forces are *a priori* knowledge" ("Alle Grundvorstellungen über das Wesen der Materie und ihre Kräfte sind Erkenntnisse *a priori*" [MN 443]). This challenges Kant's limitation on the force of attraction. Mathematical *Naturphilosophie* aims toward "a survey of the highest explanations of natural philosophy" ("eine Uebersicht der höchsten naturphilosophischen Erklärungsgründe") in phoronomy, dynamics, mechanics, and phenomenology that, in contrast to Kant's, provide a "much larger multiplicity of metaphysical and mathematical explanations" ("viel größere Mannigfaltigkeit metaphysisch-mathematischer Erklärungsgründe" [MN 621]).

Mathematical Proof in Newton's Rational Mechanics

In a long tradition since antiquity, the motion of the planetary bodies was characterized as a continual circular motion. Already in the middle of the 1660s, some twenty years before the publication of the first edition of the *Principia* (1685), Newton had independently of Christiaan Huygens illustrated the relation of orbital velocity and centrifugal force using the model of a body that left its orbit and passed into a state of straight continual motion; he determined this relation as *v2/r*, whereby v is the orbital velocity and *r* is the radius of a circle (Brackenridge and

Nauenberg 88). In a manuscript from these years, Newton uses § 36 (lemma 30) from the third book of Euclid's *Elements* (73–74). The relation of acceleration and force is traced back to the relation between areas. We encounter this task and its solution again in proposition 4 of the *Principia*, which shows that Newton had never given up this methodical approach.

Initially only the so-called "direct" problems for bodies moving in similar orbits could be solved. In the case of direct problems, the orbit and center of force is given, and the mathematical expression of the force can be determined independently from the mass of the observed body. But what does it look like when the motion is not uniform and does not follow a circular orbit? Newton's main focus in Book I is to discover the mathematical expression of the centripetal force for unequal motion in elliptical orbits. In proposition 6, Newton utilizes Kepler's law of equal areas (which is proven in proposition 1) to demonstrate that the centripetal force that works on a body that orbits in a nonresistant space around a stationary center point is measured through the deviation of the curve from the tangent in a given time.

In *Propositio* 1, the necessary theorem of equal areas is proven in the following way: if a body moves on a straight line *A*, *B*, *c* according to its initial impulse, and if a point *S* that is not on the line is assumed, the triangles *SAB* and *SBc* would have the same areas due to the fact that they have the same height (measured through the perpendicular from *S* onto the line *A*, *B*, *c*) and in each case have the same base (measured by the time the body needs to travel from *A* to *B* and *B* to *c* (Prop. 1, Coroll. 1). If we now assume that a force pulls a body at point *B* in direction *S*, then the body would continue its orbit not in direction *c* but in direction *C*. Since the new triangle *SBC* has the same area as *SBc* and *SAB* (the same base and height), it follows that it also has the same area. Let's now further complete the angle

ABC to the parallelogram *ABCB'* with diagonals *AC* and *BB'*. If the given time Δt is randomly small, the diagonal *AC* becomes the sine of an arc *ABC* and ½*BB'* becomes the *sagitta* of the arc (this expression describes the perpendicular from the center *V* of the sine to the center *B* of an arc).[15] In an indefinite smaller time, the *sagitta VB* becomes proportional to the centripetal force *Fz* (Prop. 1, Coroll. 4). Further distance covered on the curve increases directly proportional to the square of time Δt^2 (Lemma 11, Coroll. 2, 3). The length of the *sagitta* is therefore calculated from the force *F* multiplied with Δt^2; and accordingly $Fz = VB / \Delta t^2$ (Prop. 6; Cohen 319–20).

In *Propositio* 6, *Corollarium* 1, Newton assumes that time is proportional to a given area beneath a curve. He therefore constructs a curve *APQ* with tangent *ZPR* in *P*. From *P* runs a line to a point *S* from the basic line of the half circle beginning in *A*. *QT* is a perpendicular from point *T* on the axis to point *Q* on the curve. *R* is a point on the tangent such that *QR* is parallel to *SP*. Let's now accept the result of the construction from proposition 1, that the divergence of the curve from the tangent that corresponds to the length of *QR* is exactly the sagitta of an arc *QPQ'*, which has twice the length of *QP*. If we consider that the distance *QP* can be thought of as randomly small, it becomes clear that *SPQ* can be looked at as a triangle. $SP \times QT$ is therefore proportional to *PQ* and $SP^2 \times QT^2$ is proportional to the arc *QPQ'*. The centripetal force is therefore proportional to $QR / SP^2 \times QT^2$.

The procedure of parabolic approximation provides a dynamic measure for Newton's centripetal force (dynamic because it is developed from the effect of the force). After the relation between distance and time and the relation between the curvature of the curve (deviation from the tangent in a given point) is determined, Newton can demonstrate that the centripetal force decreases in the inverse square of the distance, which explains the changes in the acceleration of a body on an ellipsis, whereby the center of force lies in a focal point of the ellipsis. Additionally, in proposition 11 the result of proposition 6 is connected with some characteristics of the ellipsis.[16] The most important quantity is a constant, the *latus rectum* L, which is defined as the relation between the vertical half axis BC and the horizontal half axis AC from the perimeter to the center of the ellipsis, whereby $L = 2BC^2 : AC$ is valid. Newton solves the direct problem of an ideal planetary motion on an ellipsis by demonstrating that the relation of QR to QT^2, discovered in proposition 6 by infinitely small divergences of the tangent of the curve, approaches the value $1/L$ (Brackenridge and Nauenburg 111). Since L is a constant in every ellipsis, Newton can infer that the proportionality of the centripetal force to $QR / SP^2 \times QT^2$ exists for the movement of a body on an ellipsis. Because of the introduced observation of limit, QR / QT assumes approximately the value 1 ($QR = QT$); it follows that the centripetal force decreases in the relation $1 / SP^2$, whereby SP is a radius vector to one of the focal points.

Inductive Proof and the Fourth Methodical Rule

In Book III (*System of the World*), Newton argues that gravitational force is universal by tracing back empirical phenomena to the laws of rational mechanics. The idea that an empirical proof of mathematically discovered hypotheses is necessary, whereupon empirical phenomena are explained through mathematical theories, represents for Fries the difference between physics as science and as descriptive natural history. The question of which empirical statements can provide the foundation and how they can be proven is therefore of substantial significance. Newton assumes that Kepler's law of equal areas and his harmonic law (the relation between the period T and the radius

r of a body, which under given conditions moves around a stationary center, corresponds to the equation $T^3 \sim r^2$) are universal empirical laws. Through equivalence, which has its foundation in Book I in propositions 1 and 2, that an expansion of the distances on the curve presupposes a displacement of the center of force in the direction of the motion and to the contrary, Newton is able to articulate the law of equal areas as the measure of the centripetal alignment of the attractive force to a center, presuming that this is stationary (Harper 176).

We will not look at the fact that the empirically ascertainable movement of the moon does not correspond approximately with the gravitational theory; we ask instead, which inference types can be utilized? First, Fries's assessment that rational mechanics in the application of Newton's "system of the world" does not concern itself, in a strict sense, with a constitutive theory proves itself completely correct. It is surely not a mathematical construction of an object in purely intuitive space, as one could at the very least claim with Kant and Fries's sense for geometrical objects. The proof is rather based on knowledge from empirical intuition (*Anschauung*)—that becomes, in terms of the formation of scientific hypotheses, standardized (a scientific hypothesis is a lawful hypothesis of the logical form of a totally quantified subjunctive statement). With the standardization of observational data, probable deduction plays a role in the elimination of observational mistakes through the investigation of averaged observational values and through the explanation of abnormalities. This becomes particularly clear when Newton discusses the different results of the determination of the average distance of the moon from the earth. The observational data diverge from 56.5 (Tycho de Brahe) to 62.5 (Athanasius Kircher) times the earth's diameter. Based on his works on probability theory, Fries recommends the application of the sum of the smallest squares to eliminate observational errors. This method, which relativizes the strongly divergent results in contrast to those nearest the arithmetical mean of available results, was not yet known to Newton. He provides a componential interpretation for the relatively strongly divergent observations of Tycho and assumes a distance of sixty earth diameters, which is about the mean of all data provided. Nevertheless, here is the systematic point where probabilistic deductions of probability theory can be deployed for explanatory theories. Newton does not use probability theory to confirm hypotheses. The later theory of errors was also not yet available. Considerations on probability only play a very minor part.

Regarding the questions of whether Newton had seen his argumentation in the sense of a proof of the existence of a universal gravity and of what the word *proof* therefore means, it is imperative to take a look at the fourth methodical rule that Newton had added in the second edition of the *Principia*:

> In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions. (796)

Newton argues here that a metaphysical critique, derived from simple "hypotheses," cannot refute an inductive proof. Only inductive presuppositions or "phenomena" are positioned as revisable. At the same time, Newton allows critique through counter-evidence. Both the inductive presuppositions and the inductive arguments are principally open to criticism. Newton does not consider it a legitimate form of criticism that his theory is ultimately derived from justified assumptions of Cartesian metaphysics. He also rejects the argument that gravitational theory is invalid because, according to rationalist criteria, it is unproven.

Newton also rejects the objection from the camp of skepticism that, for every theory, any number of contrary and similarly well founded theories can be offered that require a suspension of judgment. Newton further rejects eliminative induction, a line of argument that had been well established since Bacon and utilized later by Mill as an exemplary form of demonstration in the empirical sciences, whereupon a hypothesis is supported through its refutation of available alternatives (Lakatos 221).

The fourth methodical rule ostensibly seeks to distance itself from both of the great philosophical schools of the seventeenth century—namely, rationalism and skepticism. Newton would like to protect his program of inquiry, insofar as he defends it against the claims of the schools and their futile disputations. If one takes a closer look, Newton appears to follow a persuasive strategy against the philosophers and mathematicians influenced by rationalism—for example, Huygens's objection that the theory of gravitation is unproven and therefore invalid. At any rate, the fourth rule certainly does not only polemicize against Descartes. It further plays a role in the argument about priority with Hooke, Wren, and Halley in which inductive proof is presented as the pre-eminent foundation for the empirical sciences. It also relativizes, due to direct pressure from Halley, his admission in the preface that Wren, Hooke, and Halley discovered the law of gravitation independently of Newton, because a hypothesis without inductive proof does not really constitute a discovery according to the fourth rule.

But how are the two forms of criticism that Newton presents as admissible to be evaluated? It must be possible to falsify theories through factual statements that contradict their presuppositions. This commitment does indeed sound convincing, but it is not a particularly good argument. The facts or basic propositions that Newton offers cannot be derived from theory.

Kepler's laws, which Newton postulates as a generalization of observational data and that can be proven through the theory of gravitation, are in reality essentially false, a fact that was common knowledge among natural philosophers at the end of the seventeenth century.[17] Newton did not actually have to wait for falsifying factual statements since these were already at hand in his own records. Newton also appears disappointed about the divergent results of the movements of the moon; however, he was not prepared to revoke the case of the moon, probably because it was important in the argument about priority. We must presume, however, that Newton did not look upon factual findings as possible falsifications but rather was inclined to see them as exceptions to a theory (and to be able to formally rescue them).[18]

How is it possible that the proof of induction itself should be criticized? The explanation can only be that Newton himself had not considered it a truthful inference. Even if no falsifying facts are known, the conclusion that phenomena provide a universal law of gravitation is a logically invalid generalization. Such a critique can hardly be concerned with a logical proof of validity because it does not substantiate a single inductive proof and, at the same time, would render all inductive proofs invalid.

If we take a closer look at the preceding analysis, it becomes evident that Newton did not understand inductive proof as a process that could be justified in a logical or probabilistic way. It is rather a combination of several forms of disclosing evidence whereby mathematical constructions (apodictic proofs) are joined together with other forms of explanation. Fundamental for Newton's procedure in its rational or conceptual part is the conversion of (infinitesimal) calculus by way of observing limits (*Limesbetrachtungen*) in area and distance equations. The evidence for the conclusion can no longer be found in the logical relation between the propositions (that premises imply logically the conclusion) but rather in the immediate ("pure") intuition (*Anschauung*) that connects the process of construction and its product. This leads to the formation of heterogeneous propositions, as we find in a prominent place in the statement in proposition 11, which defines the centripetal force "like" the inverted square of the distance SP. In doing so, a proportion between incommensurable magnitudes is declared that clearly shows that the basis of the agreement cannot be the logical relation between premises and conclusion. This statement is not an equation but rather an analogy similar to the construction of a figure and the probable effect of a force.

One could now object that Newton's proof does not require a geometrical representation, so as not to raise concerns about the fundamental question regarding the basis of evidence in geometrical proofs. Modern textbooks present the theory of gravitation with other operational methods. Independently of this, we find that Newton, Kant, and Fries understand geometry as *a priori* synthetic judgments and geometric proofs as constructions of objects in pure intuitive space. Formalists as well as moderate constructivists would want to question the necessity of a reference to intuitions. But if one does continue, the question still needs to be raised whether this reference to a "pure" intuition, that still blends the discourse on objects of intuition with intuitions of these objects, is still relevant.[19] In addition, it is Newton's own chosen procedure that brings with it apparent unnecessary consequences, to represent the pure figures that we cannot see through empirical figures that do not exactly correspond. Here lies the inherent pragmatic problem of how many empirical representations are required to visualize rational mechanics. It is quite clear that a complete representation of particular objects of construction (e.g., a diagram for every constructive step of an object) would have rendered the *Principia* much too extensive and unacceptable. A book, above all a textbook, is tied to an economy of representation, which Halley (as editor of the first edition) followed partly out of reasons of cost: for example, a single diagram is made available for several quite different constructions in *Propositio* 10, 11, and 16 in Book I that the reader needs to apply and even vary(!)[20] according to the different proofs. Therefore, the fundamental question is raised whenever the drawing of a figure is illustrating a step in the process of delivering a proof. It appears that this question can only be answered, if at all, by somebody who is very familiar with the procedures of the proof. From all of these considerations it appears that Newton's proof is possibly only partially replicable—and not at all verifiable.

Using Fries's philosophy of science as a point of departure, we reach a contrary result: from this perspective, only principle limitations of the proof of explanatory theories are possible since they require demonstrability of proof. The thesis of the highest approximate determinability of empiricism through speculation, which we will here abbreviate as the "Newton-Friesian approximation thesis," excludes (1) that an empirical theory (a set of universal factual statements) can be derived from a speculative theory (a set of mathematically grounded "hypotheses" or assumptions) and (2) that there is a probabilistic explanation for the connection of speculative and empirical theory. Because the possibility of connecting speculative theory with experience is dependent upon maxims that are founded in ideas without empirical meaning, the evidence of a natural scientific theory (approximate constitutive) is dependent, one way or the other, on the representation of this connection with particular examples. If we think through Fries's theory of science to the end, then, according to Fries, the point in the explanation where a representation of theory for empirical phenomena becomes necessary has to be recognized as the limit of theoretical constitutiveness of the phenomena.

If, in regard to the assumption that Newton's mechanics and theory of celestial motion presents for Fries a maximal approximation to the scientific ideal of a constitutive theory, we ask what kind of inference types are part of this theory, we can ascertain that all five different inference types—logical inference, probabilistic inference, plausible inference, enthymeme, and pragmatic presupposition—become necessary for the construction of an approximate constitutive theory. The explanation for this pluralism of inference types is that at some point in a theory of natural science, according to Fries, a representation of a particular object has to take place. A loss of validity in the process of representation is not to be feared because Fries had already eliminated certistic assumptions in notions of "axioms."[21] It can be established, according to Fries, that a point of view where constitutive theories must be comprised of a logical proof of validity and where regulative theories are merely plausible completely misunderstands the difference between constitutive and regulative theories—and therefore also Newton's proof of universal gravitation. A closer examination shows that intuition plays a different role in constitutive and regulative theories. Constitutive theories are distinguished from regulative theories only in that they make use of laws of a higher order, an explanation that follows Kant's and Fries's concept of mathematics in regards to a pure intuition; it follows that this cannot be empirically tested and corrected. Regulative theories, on the other hand, are dependent on the reflection of phenomena of empirical, spatial-temporal intuition.

From a Regulative to a Constitutive Theory: Electricity and Magnetism

After demonstrating Fries's understanding of the hermeneutic effectiveness of the pluralistic doctrine of method by using Newton's chain of arguments for the explanation of universal gravitation, we will finally investigate a question that engaged Fries's attention: namely, the problem of the heuristic function of mathematical *Naturphilosophie*. The question of what, in Fries's understanding, a pluralism of methods can achieve in contrast to the architectonics of a unitary system in Kant's view is essentially decided in the field of heuristics. Within an identification of science and system (Pulte 103), however, heuristics does not have a place in science but is relegated to a completely separated aesthetic worldview. Fries's pluralism of methods, on the other hand, introduces aesthetic elements into a scientific conception of the world.

In terms of Fries's philosophical approach, the doctrine of electricity around the turn of the nineteenth century must be considered with particular attention, since Galvanism and the Leyden (Kleistian) jar considerably improved scientific proof through phenomena. With Coulomb's law especially[22]—which stipulates that the electric force declines, like gravitation, as it approximates the inverse square of the distance—electricity appeared to stand at the threshold of a constitutive theory. Furthermore, in the year of the publication of the *Mathematische Naturphilosophie* (1822), the possibility of a unification of magnetism and electricity through Hans Christian Oersted's experiments and observations (1821)[23] on electrically induced magnetism (in its modern idiom: a live conductor encircled by a magnetic field line; Kühn 305) appeared to be within grasp. It was Fries whose heuristic maxims of natural science had called for unification, and it was Fries whose goal it was to unify electricity and magnetism under Coulomb's law. There were, however, many obstacles to overcome.

First, mathematical *Naturphilosophie* had acquired considerable competition from another type of speculative *Naturphilosophie* that, similar to Fries's, represented empirical phenomena in the light of a speculative theory. This theory was not supported by mathematics but rather by relations of forces and their conceptual phenomena of equilibrium, a method that Schelling, who often disregarded any dependence on empirical perception, developed along with Johann Wilhelm Ritter (Weber 520–22; 523–25). According to Schelling and in contrast to Kant's conception, a polarity of contradictory forces is constitutive for matter, which enabled him to also construct *a priori* electricity and chemical processes. In a conscious distancing from Kant, it was this extension of the concept of construction from the representation of a concept in pure intuition to a general principle of procedural configuration of opposing forces that actually fulfilled a heuristic function with Oersted's discovery of electromagnetism (at least it presented for Oersted an important source of inspiration (Friedman, *Kant—Naturphilosophie* 63–64, 67).

In contrast to the idealistic *Naturphilosophie*, Fries positions himself on the defensive: although he must concede Oersted's success, he emphasizes that electromagnetism still represents a regulative and not a constitutive theory and, secondly, that it is only an approximate and not an ultimate unification of both fields of phenomena:

> Die magnetischen Erscheinungen sind durch die Oerstädische Entdeckung den elektrischen so nahe gebracht, daß eine mathematische Theorie derselben wol ganz von dem guten Glück abhängen wird, mit welchem man die Theorie der Elektricität weiter wird bearbeiten können. (MN 637)
>
> Oersted has succeeded to bring the magnetic phenomena close to the electric phenomena so that a mathematical theory derived from it will depend on luck that can be employed to further develop the theory of electricity.

Without directly getting involved in the widely held discussions concerning the basic laws of electrostatics,[24] Fries does, with the thesis that electricity consists of two radiating fluids, take a stand against Benjamin Franklin's assumption of one type of electricity:

> Zum Erklärungsgrund der elektrischen Processe bot sich uns aus der allgemeinen Theorie gleichsam von selbst das Verhältnis zweyer Arten strahlender Flüssigkeiten an, deren gleichartige Theile sich in die Ferne abstoßen, während die ungleichartigen sich aus der Ferne anziehen. (MN 634)
>
> An explanation of the electrical processes became self evident from the general theory of the relation of two kinds of radiant fluids, whose equal parts reject each other in the distance while the unequal parts attract each other in the distance.

With this the compensatory phenomena are explained as a current that flows in and out, that is, a surplus and deficit of electricity. This position is not original in the history of science. The assumption of an electric fluid that is composed of two electrical elements is proposed in Johann Tobias Mayer's *Anfangsgründe der Naturlehre* (1812), a science manual written some ten years before Fries's *Mathematische Naturphilosophie*. Mayer had already observed here that these fluids are discharged from a conductor as "bundles of rays" (*Strahlenbüschel*; Mayer § 540–41). Nevertheless, there was for a long time considerable uncertainty about the existence of two types of electricity. Johann Carl Fischer's *Physikalisches Wörterbuch* still does not decide between Franklin on the one side and Wilke and Volta on the other. All believe in the existence of two different electrical matters and explain charge and discharge of bodies through the entry of one body into the sphere of another charged body (Fischer 525). Fischer attributes to Franklin the first useful explanation of the discharge phenomena (*elektrischer Schlag*) that was demonstrated in the Leyden jars (523). Electrifying the inner surface (the conductive substance that covers the jar; Fischer 509) resulted in an electric atmosphere in the glass (*eine elektrische Atmosphäre im Glase*) that would repel the natural electricity of the outer matter. If the outer surface is connected with conductors, the repelled electrical matter can be diverted and the supplied electricity of the inner surface amassed; thus the jar becomes charged (Fischer 526–28). As Fischer emphasizes, this explanation only functions with the assistance of the dynamic system (*durch Beyhülfe des dynamischen Systems*; 526).

The dualistic explanation must not rely on the assumption of a constitutive unity of opposing forces that disperse by the charging and discharging of a body—for this very reason, this theory was preferred by Fries, although he did not comment on this. According to Fischer, the dualism does not yield less but works by other means. If the inner surface is charged with positive electricity, the same electric (charges) will be repelled at the outer surface, while the different negative electric (charges) will be attracted. Fries connects this dualism with a hypothesis about the relationship between electricity and magnetism: "The electric relationship is defined by the radiant fluid that is attracted by the heavy masses in their different degree of contact" ("Das elektrische Verhältniß wird bestimmt durch strahlende Flüssigkeiten, welche von den schweren Massen in verschiedenen Graden der Berührung angezogen werden" [MN 558–59]).

This theory does not yet correspond to the modern model of the atom for any explanation of electrical phenomena, but it is, according to Fries, justified insofar as the essential phenomena are at least factually explained and consequently cannot be dismissed *prima facie*. It does explain the following phenomena to which Fries refers: the polarity of positive and negative electricity, or charge, and the generation of heat as a compensation of these forces (Fries: "indifferent electricity," *indifferente Elektrizität*)[25]; the emergence of electrical friction as well as the classification of elements in conductors (first class) that are penetrated by the electrical fluids; conductors (second class) that are covered on the surface; and insulators, as material that attracts electrical fluid but does not distribute it (MN 634–35). Except the one question of why electricity cannot spread between two isolated surfaces, most of the known phenomena are explained (MN 636).

More interesting than his theories are Fries's methodological deliberations. When would he acknowledge the model of radiating fluids as a constitutive theory? Obviously only then when both the forces of attraction and repulsion could be described mathematically. But here are the complications. In an extensive and remarkable footnote, Fries addresses the discussion concerning Coulomb's assertion that electrical as well as magnetic forces decrease to the inverse square of the distance (thus corresponding to Newton's force of gravitation). There is one theory that rivals Fries's hypothesis of the distribution of the greatest possible unity of natural phenomena—namely, the hypothesis of Louis Paul Simon, who argues that electrical forces decrease inversely proportional to the distance. Both hypotheses—$F \sim 1/r^2$ and $F \sim 1/r$—have a completely different status for Fries. However, the competing hypothesis cannot be simply laid aside:

> Diese mathematische Theorie der elektrischen Erscheinungen würde freylich weit genügender erscheinen, wenn sich die vielversprechenden Resultate aus Coulombs Versuchen, (denen Biot noch im Jahr 1816 unbefangen beystimmte,) daß nemlich die elektrischen und magnetischen

> Kräfte im umgekehrten Verhältniß der Quadrate der Entfernung wirkten, fest bestätigt hätten. Denn dann wären wir hier zu einem einfachsten Erklärungsgrund durchgedrungen. (MN 634n)
>
> This mathematical theory of electrical phenomena would appear much more satisfactory, if the promising results of Coulomb's experiments (which Biot agreed to in 1816 without reservations) had been confirmed, that is, that the electrical and magnetic forces work in direct relation to the inverse square of the distance. With the proof we would have reached the simplest explanations of the phenomenon.

What is decisive for the choice of theory is obviously (1) the economy of the principles laid out as its basis and (2) the approximation of the theory to empirical phenomena. That the simplicity of the explanation was so appealing is indicated by a parallel commentary on Simon:

> Müssen wir hingegen Simons Nachweisungen nachgeben und annehmen, daß die elektrischen Abstoßungen im umgekehrten Verhältnis der Entfernung erfolgen . . . , so würde diese Theorie weit unsicherer, weil für dies Gesetz der Anziehung und Abstoßung noch ein anderweitiger Erklärungsgrund zu fordern bliebe. (MN 634n)
>
> If we have to concede to Simon's proofs and assume that the electrical repulsions follow in the inverse relation to the distance . . . , this theory would become much more tentative, because we would need another explanation for the law of attraction and repulsion.

That means that the divergence from the effect of gravity, not the correspondence with it, needs to be established. This position was even taken by Simon himself, who remarked that Coulomb had discovered a law with his "sophisticated experiments" (*scharfsinnige Versuche*) "that had achieved the highest degree of evidence through the universality of the principle on which it was grounded" ("welches schon durch die Allgemeinheit des Prinzips, das demselben zum Grund liegt, den höchsten Grad der Evidenz zu erhalten schien" [277]).

What was it that prevented Fries and others to simply look upon Coulomb's theory as a better explanation and to, so to speak, elevate it as a constitutive theory?

The reason—according to Simon and, to a certain extent, also Fries—was that Coulomb had not been able to illustrate his theories in experimental demonstrations. Coulomb had developed a complex torsion apparatus (*Windungsapparat*)—that is, a torsion balance that was connected through a wire with a suspension head. The restorative force was represented through the unwinding of the wire. Indeed, this construction is very sensitive. It cannot be presented as a means of measurement because unwinding is not scalable. But the movement of the elderberry pith sphere could be represented. However, Coulomb published very little quantitative data to prove the presumed hypothesis—that the restorative force equaled the repulsive force—corresponded approximately to the inverse square of the distance. Three values can be connected through a curve that represents this function in a graph. Asking the question of whether there are alternative curves that represent the repulsive force appears to be quite justified.

Instead, Simon utilizes normal balancing scales that bear on one side an elderberry pith sphere and on the other side a compensating weight. The reason for the choice of apparatus is extremely interesting. As Simon stresses, "my main intention in the choice of an apparatus was simplicity in order to represent the expected results as clearly as possible" ("ist die möglichste Einfachheit stets mein Hauptgesichtspunkt bei der Wahl der Apparate, um durch sie die erwarteten Resultate möglichst unverhüllt darzustellen" [278]). This declaration clearly shows that the function of the experiment was the most successful illustration of the results anticipated from the theory. Next to the torsion balance, another apparatus is set up on which the same elderberry pith sphere is affixed. Both are positively charged, which causes the arm of the scales with the elderberry pith sphere to move down. A gauge on the scales measures the gradation of the deflection. The weight at the other end of the scales plus the restorative force of the scales indicates the force of repulsion that is created through the contact of the equally charged elderberry pith spheres.

The data appear to differ markedly from Coulomb's results. Nevertheless, these differences do allow themselves to be explained and are therefore irrelevant. Simon had measured from the surface of the sphere. But if it is measured—as it ought to be—from the centre of the sphere, then similar experimental results for both Coulomb and Simon are achieved. These results do not have any further methodological significance for us. The discussion shows that the main reason that Coulomb's explanation could not be seen as a constitutive theory of electrostatics was, according to Simon as well as to Fries, the insufficient representation of phenomena. Therefore, Fries had to insist on the position that his preferred theory simply had not been refuted, "as long as Coulomb's experiments had not been dismissed and the reason of his errors not proven" ("so lange Coulomb's Versuche nicht beseitigt und der Grund seines Irrthums nachgewiesen ist" [MN 634n]).

In summary, we can argue that a regulative theory is a theory in which the unity of the phenomena must be conjectured under a law developed from the empirical intuition of phenomena. As soon as this deficit is overcome, it transforms itself into a (approximate) constitutive theory. That happens precisely at the moment when the simplest explanation that mathematical speculative theory has to offer can be achieved and represented with a particular example.

Towards a Metacritique of Critical Rationalism.

After the discussion of the relation between *Naturphilosophie* and mathematics, on the speculative side, and natural science and the study of nature, on the empirical side, and with regard to the explanation of a constitutive and a regulative theory, it is necessary to conclude with a critique of some of the positions of modern theory of science towards Newton.

The certistic point of departure of mathematical *Naturphilosophie* has led to misunderstandings with respect to its scientific criteria. Science, according to these criteria, must establish mathematical principles of an area of reality. We can use the expression "area of an object" (*Gegenstandsgebiet*) in an unspecified manner and presume that everyday language categorizes the world in terms of areas of objects in which phenomena of a similar kind—for example, colors—are grouped. A theory *T* of an area of an object can therefore, in the sense of a mathematical *Naturphilosophie*, only be considered a science when *T* has a small number of axioms that are universally true; furthermore, all theorems in *T* must be logically implicated when these axioms and theorems are necessary for the explanation of observations of objects in a specified area, and when they present ontologically necessary structures of the area of an object (Simon 49, 56–57). The problem of reception of Newton's rational mechanics can be found in the fact that, from his time on, Newton's criteria of science appear to identify the concept of science with an axiomatic deductive system. Newton's own explanations, namely the motion of the planets, did not fulfill an essential prerequisite for an axiomatic structure that all universal statements of theory and laws of motion must logically follow. Innumerable writers, among them P. Duhem,[26] K. R. Popper,[27] and I. Lakatos,[28] have subsequently provided critical commentaries on Newton as a methodologist, wherein the influential derivation is central. Above all, critical rationalists turn to the immunizing character of the methodical rules that Newton amended in the second edition of the *Principia*. The combination of an inductive proof of basic propositions (here Kepler's three propositions) with their axiomatic grounding appears to rule out any critical test, especially the falsification of laws based on empirical facts.

It has been established above as fundamental insight of the Friesian doctrine of method that mathematical theories can only approximately determine empirical phenomena. Strictly speaking, it is misleading, as Helmut Pulte has shown, to speak with regard to classical mathematical *Naturphilosophie* of an application of mathematics to phenomena (*mathesis applicata*); it is correct to say that certain phenomena such as free fall and acceleration can be looked upon as mathematics and are therefore both mathematical and empirical (*mathesis mixta*; Pulte, *Axiomatik* 42–43). Correspondingly, the variants of a mathematical *Naturphilosophie* since Newton indicate, on the one hand, the idea of a complete certainty of laws of a higher level, like Newton's *leges motu*, that establish empirically universal laws; on the other hand, they also imply the notion that empirical laws are necessarily deficient and flawed. The combination of both conceptions excludes a derivation of empirical statements from laws of the higher level—the principle reason why natural science cannot be constructed as a deductive system of axioms.

The above criticism overlooks what constituted Newton's essential insight that *a priori* laws of a higher level could only establish the phenomena by approximation. They never completely determine the singular case—for example, the observation of a planet's position. This explains the apparent contradiction that *a priori* statements of law ought to be valid although the empirical phenomena cannot prove it; this is something that causes difficulty with almost all commentators. Indeed, new empirical results cannot correct theories; however, the approximation of (speculative) mathematical theory with the empirical phenomena can be stated ever more precisely.[29] This approach also explains how it is at the same time possible that confidence in Newton's gravitational law is not shaken even though his theory as universal physics was replaced.[30]

By paying tribute to Newton's scientific discovery and methodology, Fries's recognition that laws derived from theories that are independent of experience cannot determine experiential phenomena (strictly speaking they cannot do that at all) makes a reconstruction of Newton's proof of his universal gravitational law possible. Because critics like Duhem, Popper, and Lakatos have paid little attention to the approximate character of mathematical natural science, they have also overlooked the fact that evidence of the theory should not emerge exclusively from logical proof of validity but rather from an interconnection of representation and proof.

NOTES

1. Pulte, *Axiomatik und Empirie* 239. In this essay, I have incorporated a number of Pulte's suggestions from the manuscript version of my *Habilitationsschrift, Heuristik und Wahrscheinlichkeit in der logischen Methodenlehre* that could not be adequately considered in the printed version. In addition to Pulte, I would like to thank Jan Frercks and Erdmann Görg for innumerable valuable suggestions.

2. The source of this version is Kuno Fischer's lecture "Die beiden Kantischen Schulen in Jena" (1862).

3. Manfred Kuehn characterizes the philosophy of Hamann, Herder, and Jacobi as "counter-Enlightenment" (11); this is certainly not anti-enlightenment, but rather an alternative critique of reason.

4. To use the terminology of modern theory of science, Fries reacts to the so-called Münchhausen Trilemma, which says that every judgment results in an infinite regress, a dogmatic rupture of the judgment, or in a vicious cycle. In the tradition of transcendental philosophy from Kant and Fichte to Apel, it is different: there is not an attempt at a final judgment except with the referral to non-revisable frames of reference. The concept of belief covers two aspects: unsubstantiation (*Unbegründbarkeit*) and non-revisability (*Unrevidierbarkeit*). Fries does not consider that another framework could possibly have been chosen. That puts him apart from the conventionalism of the later Carnap.

5. An outline of mathematical (L. Kreiser), anthropological (I. Jahn), biological (O. Breidbach), theory-of-science (H. Pulte as well as U. Charpa), and heuristic (G. Gabriel) aspects of Fries's philosophy and the history of its reception in Apelt, Reichelt und Schleiden are provided by contributions in Hogrebe and Hermann.

6. See Popper, *Logik der Forschung* 60; see also 61, where Popper in his own interpretation sees Fries's psychologistic position leading to a positivism with the comment "Most of the time, the problem is not even addressed" ("Meist aber wird das Problem gar nicht so weit aufgerollt").

7. Fries's *Die mathematische Naturphilosophie* is in following references abbreviated as "MN."

8. The widely held opinion that the dynamic concept of matter in Kant and in *Naturphilosophie* was directed against Newton's atomism appears to be based on Goethe's and Schelling's conception of *Naturphilosophie*, although this often goes unnoticed. The dynamic concept of matter that construes it from a relation of opposing forces (attraction and repulsion); this opens the option to conceive matter as filling space, with the goal of introducing a theoretical grounding of the presuppositions of Newton's mathematical philosophy of nature: "Kant's philosophy of nature, in most relevant respects, should rather be viewed as a culmination of the Newtonian tradition" (Friedman, "Kant—Naturphilosophie—Electromagnetism" 52). Post-Kantian *Naturphilosophie* allows itself to be compared to a unity of opposing forces—namely dynamic and mathematical *Naturphilosophie*; its relation to Newton depends upon how these forces can be equalized through intuition und perception (Schelling, Goethe) or through analysis of language and concepts (Fries).

9. The terms *Anschauung* and *Anschauungsformen* are translated here as

"intuition" and "forms of intuition."

10. Fries considers this as valid for the concept of form that is presented in a pure morphology: "We have to assert that the entire understanding of the world according to form and motion is originally one of mathematics" ("Wir müssen behaupten, daß die ganze Weltansicht nach den Gesetzen der Gestalt und Bewegung eine ursprünglich rein mathematische ist" [MN 23]). In Fries's terminology, the mathematical constructions of motion and form, taken in a narrow sense, are called natural science or physics.

11. See Fries's *System der Logik*, which is abbreviated in subsequent references as "SdL." On the one hand, Fries holds on firmly to Kant's concept of logic as a formal canon of reason (without any content). Logic in a narrower sense is for him the tautological reshaping (*Umformungen*) of signs. Differing from Kant and with emphasis on the perspective of formation (*Genese*) rather than validity, he gives prominence to the logical reshaping of the independence of formal thinking according to anthropological principles. He further observes the pure forms of thought as determining the rational part of human cognition, especially for logical clarification through concepts. Fries's *System der Logik* correspondingly covers (1) an anthropological logic (§§ 4–39); (2) a philosophical logic (formal logic in a narrow sense, §§ 40–117), which is analyzed in its second part, the cognitive function of applied logic; and (3) a doctrine of method (§§ 116–34) that concerns itself with empiricism, speculation, and their combination in induction as well as with didactic questions.

12. MN 7–8: "This has been most successfully accomplished in the doctrine of gravity; less so in the doctrines of sound, light, heat, electricity, and magnetism; the relation of bodies, the process of crystallization and the chemical solutions and depositions" ("Dies ist am vollständigsten gelungen in der Lehre von der Schwere, stuffenweise hingegen immer weniger in den Lehren vom Schall, vom Licht, von der Wärme, von der Elektricität und dem Magnetismus, vom Zusammenhang der Körper, dem Krystallisationsproceß und den chemischen Auflösungen und Ausscheidungen").

13. Friedman, *Kant and the Exact Sciences*. See especially chapter 3, "Metaphysical Foundations of Newtonian Science." One can confidently say that to this day the criticism of the postulate of absolute space is an important achievement in classical mathematical *Naturphilosophie*. Newton's theory can be formulated in different ways, and not every variant of Newtonian space-time postulates an absolute space. Earman und Friedman claim that the system of inertia is not stringently postulated, that motion can only be determined with the help of an absolute immovable point: "The objection to absolute space is not that it is a mysterious metaphysical entity . . . ; rather, the objection is that it is superfluous since absolute acceleration need not be defined as acceleration relative to absolute space" (333–34).

14. See the reference of the editors, Gert König und Lutz Geldsetzer, in the prefatory remark to vol. 13 of the *Sämtlichen Schriften*: Fries wishes to stress, on the one hand and more forcefully than Kant, the *a priori* nature of mathematical *Naturphilosophie* and, on the other hand, its hypothetical character (MN 25).

15. Newton's geometrical terminology deviates in important instances from what is generally accepted today. A rectangle characterizes not only a quadrilateral with four right angles but also its area, the product of its sides. The basis of trigonometry is the idea not of an angle, with which we are familiar today, but rather of its arc. A sine is the line that connects both end points of an arc. The sagittal, or flipped sine (*sinus versus*), is the perpendicular line that runs from the center of the sine to the arc.

16. Newton presumes that this is already known. Cf. Cohen for an insightful reconstruction (330–31).

17. See Lakatos 225: "But Kepler's three laws were wrong and that was widely known in 1686: the planets do not move in perfect ellipses; changes in Jupiter's and Saturn's motion do not correspond to Kepler's 'second law'; and the motion of the moon deviates considerably from Kepler's simple system" ("Aber die drei Keplerschen Gesetze waren ja falsch; und um 1686 war das auch allgemein bekannt: daß die Planeten keine sauberen Ellipsen beschreiben, daß Geschwindigkeitsänderungen bei Jupiter und Saturn dem Keplerschen 'zweiten Gesetz' nicht entsprechen und daß die Bewegung des Mondes von dem einfachen Keplerschen Schema ganz erheblich abweicht").

18. See the information in *Opticks*, query 31 (Newton 116): "But if at any time afterwards any Exception shall occur from Experiments, it may then begin to be pronounced with such Exceptions as occur."

19. The expression *Anschauungsform* ("form of intuition") covers (1) the intuition of figures, (2) intuitive judgments on figures, (3) statements on pure geometrical forms (of which we have no intuition). On Kant's particular mode of expression, see Stekeler-Weithofer 31–33.

20. See Cohen 300: "In Prop. 10, the force is directed toward the centre of the ellipse, and so the displacement *QR* (the side of the parallelogram from the tangent and radius, *TvZ*) should be parallel to the diameter *CP*; in Prop. 11, however, the force is directed toward the focus *S*, and so the displacement should be parallel to the focal radius *PS*."

21. That this is a significant displacement by Kant follows from Kant's limitation of "actual science" to apodictic, assertable principles. See *Metaphysische Anfangsgründe*, *Gesammelte Werke*, IV 467.

22. Coulomb had actually only attempted what Priestley had already expressed

as a conjecture that could be proven experimentally. Cf. Kühn 296.

23. See Oersted.

24. For a comprehensive account, see Heering.

25. Based on Coulomb's law of the inverse square of the distance and declining force of attraction, Fries obtains the following "law of electric polarity and compensation" ("Gesetz der elektrischen Entgegensetzung und Ausgleichung" [MN 559]): "Equal electric charges repulse each other, unequal attract each other and will mix where there is no obstacle" ("Gleichartige elektrische Spannungen stoßen einander ab, ungleichartige ziehen sich an und werden sich mischen, wo kein Hinderniß ist").

26. See Duhem 257. Duhem argues that Newton's acceptance of fixed central bodies contradicts the third law of motion. For criticism of Duhem as well as of Popper (see the following footnote); see Pulte, *Axiomatik und Empirie* 103.

27. Popper, *Objektive Erkenntnis* 206n8. Popper asserts that Newton's variable gravitational acceleration contradicts Galilei's acceptance of a constant gravitational acceleration.

28. See Lakatos 225. Lakatos argues that Newton's propositions in Book I are represented as a "coarse model . . . that does not satisfy the presuppositions, especially the third law of dynamics" ("das den Voraussetzungen, insbesondere dem 3. Gesetz der Dynamik, nicht erfüllt"). Newton the great scientist was aware of this problem, whereas Newton the poor methodologist passed over this problem.

29. See Pulte, *Axiomatik und Empirie* 103: "Different from Duhem and Popper and in spite of their criticism I see Newton's great achievement in his construction of a network of notions and mathematical laws deductively, which holds up amidst the multitude of empirical proofs; it even allows for further detailed work so that the individual case can be approximated" ("Anders als Duhem und Popper und trotz deren Kritik sehe ich die großartige Leistung Newtons gerade darin, in deduktiver Art ein 'Netz' von Begriffen und mathematischen Sätzen aufzubauen, das unter der Fülle des empirischen Belegmaterials nicht reißt, sondern es sogar gestattet, die Maschen so zu verfeinern, daß der Einzelfall . . . noch approximiert wird)."

30. See Unzicker.

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