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Kant's Philosophy of Chemistry

DISSERTATION

submitted in partial satisfaction of the requirements  
for the degree of

DOCTOR OF PHILOSOPHY

in Philosophy

by

Michael Bennett McNulty

Dissertation Committee:  
Associate Professor Jeremy Heis, Chair  
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2014



## DEDICATION

For James, Eulalie, George, and Yvonne.

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have overlooked. Penelope Maddy (and her Second Philosopher) has profoundly influenced how I approach philosophy; I am lucky for the opportunity to learn from her in a formative stage of my philosophical career.

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## ABBREVIATED CITATIONS

I use the following abbreviations for works by Kant:

Anth	<i>Anthropologie in pragmatischer Hinsicht</i>
Br	<i>Briefe</i> (volumes 10–13 of <i>Kants Gesammelte Schriften</i> )
DI	<i>Meditationum Quarundam De Igne Succincta Delineatio</i>
DP	<i>Danziger Physik</i>
FEV	“Die Frage, ob die Erde veralte, physikalisch erwogen”
GNVE	“Geschichte und Naturbeschreibung der merkwürdigsten Vorfälle des Erdbebens, welches an dem Ende des 1755sten Jahres einen großen Theil der Erde erschüttert hat”
Log	<i>Jäsche Logik</i>
KpV	<i>Kritik der praktischen Vernunft</i>
KrV	<i>Kritik der reinen Vernunft</i>
KU	<i>Kritik der Urteilskraft</i>
MAN	<i>Metaphysische Anfangsgründe der Naturwissenschaft</i>
MS	<i>Die Metaphysik der Sitten</i>
NTH	<i>Allgemeine Naturgeschichte und Theorie des Himmels</i>
Prol	<i>Prolegomena zu einer jeden künftigen Metaphysik</i>
OP	<i>Opus Postumum</i>
Refl	<i>Reflexionen</i>
V-Lo/Blomberg	<i>Blomberg Logik</i>

V-Lo/Wiener        *Wiener Logik*

V-Met/Dohna        *Metaphysik Dohna*

V-Met/Volckmann    *Metaphysik Volckmann*

Citations of KrV will refer to the standard A/B pagination. All other citations of Kant's works will refer to the Akademie edition volume number and page number(s). For English translations I use Young's V-Lo/Blomberg and Log (in Kant 1992), Förster and Rosen's OP (Kant 1993), Gregor's KpV (in Kant 1996), Guyer and Wood's KrV (Kant 1998), and Friedman's MAN (Kant 2004). All other translations from German are my own.

I use the following abbreviations for other works:

AKN                *Anleitung zur gemeinnützlichen Kenntniss der Natur* (Karsten 1783)

OL                 *Œuvres de Lavoisier publiées par les soins du Ministère de l'Instruction  
publique* (Lavoisier 1864–93)

Citations of AKN refer to its reproduction in the 29<sup>th</sup> volume of the Akademie edition of Kant's collected works. Citations of OL, Gehler (1787–95), and Partington (1961–70) refer to the respective volume numbers and page numbers.

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ABSTRACT OF THE DISSERTATION

Kant's Philosophy of Chemistry

by

Michael Bennett McNulty

Doctor of Philosophy in Philosophy

University of California, Irvine

Associate Professor Jeremy Heis, Chair

In his *Metaphysische Anfangsgründe der Naturwissenschaft* (1786), Immanuel Kant claims that chemistry is an *improper*, but *rational*, science. In this dissertation, I explain Kant's conception of chemistry by situating his discussions of the science with respect to his theoretical philosophy and his scientific context.

In the first chapter, I explain why Kant believes chemistry to be an improper science. In the *Metaphysische Anfangsgründe der Naturwissenschaft*, Kant maintains that the *a priori* application of mathematics in proper science distinguishes it from improper science. Because of his opposition to mechanical philosophy, which reduces natural phenomena to mathematically expressible qualities, Kant took the application of mathematics to be a nontrivial problem. He contends that there must be *a priori*, metaphysical principles that validate the application of mathematics to a proper science. Ultimately, Kant argues that the forces of chemistry, unlike those of physics, are incapable of such *a priori* validation, making chemistry a merely improper science.

The second chapter concerns chemistry's status as a rational science. I contend that rational sciences, unlike mere sciences, are capable of genuine, causal laws for Kant. I argue that

there are different kinds of causal laws in different sciences: whereas the laws of physics are conditions for the possibility of experience of external objects, the laws of chemistry are quite different. Kant believes that the cognitive faculty of reason postulates chemical elements as the absolute, fundamental bearers of chemical powers, and that chemical laws are possible only insofar as they follow from the nature of these postulated entities.

In the last chapter, I argue that Kant continues to believe chemistry to be an improper, though rational, science in his unfinished *Opus Postumum* (ca. 1795–1803). In this work, after his exposure to Lavoisier’s chemical revolution, Kant claims that the existence of the caloric can be deduced *a priori* and that the elements can be enumerated *a priori*. Nevertheless, I contend that the newly added *a priori* components neither belong to chemistry nor validate the mathematization of the science. Rather, they are parts of the transition (*Übergang*), which explains the systematicity of natural science.

## INTRODUCTION

References to chemistry litter Kant's philosophical corpus. One of the most important and well-known tracts of Kant's writings is the B-edition preface to his KrV. Therein, Kant depicts metaphysics, the queen of the sciences, as a battlefield in which no ground is won or lost and upon which philosophers fruitlessly grope among mere concepts (KrV, Bxi). In contrast, mathematics and natural philosophy progress; their practitioners agree on the fundamentals and work together to achieve their respective ends. These disciplines succeed, for they, in contrast to metaphysics, have been brought to the *secure path of science*: mathematicians and natural philosophers recognize that reason has insight only into what it puts into its object. Kant famously calls attention to exemplars that first set natural philosophy on its secure path.

When Galileo rolled balls of a weight chosen by himself down an inclined plane, or when Torricelli made the air bear a weight that he had previously thought to be equal to that of a known column of water, or when in a later time Stahl changed metals into calx and then changed the latter back into metal by first removing something and then putting it back again, a light dawned on all those who study nature. They comprehended that reason has insight only into what it itself produces according to its own design, that it must take the lead with principles for its judgments according to constant laws and compel nature to answer its questions, rather than letting nature guide its movements by keeping reason, as it were, in leading strings; for otherwise accidental observations, made according to no previously designed plan, can never connect up into a necessary law, which is yet what reason seeks and requires. (KrV, Bxiif.)

While Galileo and Torricelli's contributions to the scientific revolution are heralded to this day, Kant is also impressed by the work of the chemist Georg Stahl. Stahl is the inventor of the phlogistic theory of chemistry, which postulates phlogiston as the hypothetical principle, whose inherence in and expulsion from substances explains all inflammability phenomena. Here Kant praises Stahl alongside Galileo and Torricelli particularly for their use of experiments in natural philosophy. In Kant's eyes, this was the crucial development in natural philosophy that placed it

on the secure path of science. With the advent of experimentation, natural philosophers realized that to learn from nature one ought not act as a mere passive receptacle for experiential information. Rather, the natural philosopher ought craft hypotheses and artificial situations that test her hypotheses. The natural philosopher is thus an active participant when learning from nature: she can only receive answers to questions she herself asks of nature. Kant, of course, famously leverages his conception of the secure path of science into a new methodology for metaphysics. To achieve progress in metaphysics, Kant proposes his Copernican Revolution, according to which, humans—specifically, our cognitive faculties—play an active role in the production of knowledge. Thenceforth, Kant’s philosophical project in KrV focuses on these cognitive faculties and the contributions they make to experience.

This project crucially involves the distinction between things as they appear to us and as they are in themselves. Interestingly, when Kant introduces this distinction in the B-edition preface, he again appeals to chemistry, analogizing his methodology with chemical procedures.

This experiment of pure reason has much in common with what the **chemists** sometimes call the experiment of **reduction**, or more generally the **synthetic procedure**. The **analysis of the metaphysician** separated pure *a priori* knowledge into two very heterogeneous elements, namely those of the things as appearances and the things in themselves. The **dialectic** once again combines them, in **unison** with the necessary rational idea of the **unconditioned**, and finds that the unison will never come about except through that distinction, which is therefore the true one. (KrV, Bxxin.)

In the bulk of the Transcendental Dialectic of KrV, Kant discusses the endemic errors of the faculty of reason. Reason, for Kant, seeks cognition of supersensibilia—the soul, the world-whole, God—which ground our knowledge of the world.<sup>1</sup> These objects are the conditions for all of our cognitions but are themselves unconditioned. However, the assumption that we can gain

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<sup>1</sup> See KrV (Bxx; A310–38/B366–96).

knowledge of these objects through reason alone is an *illusion* that gives rise to the metaphysical excesses of dogmatic rationalism.<sup>2</sup> In the Paralogisms, Antinomy, and Transcendental Ideal, Kant means to demonstrate that we cannot have cognition of the soul, the world-whole, and God. Reason's search for the unconditioned conditions of our cognition is hence always frustrated; reason, by its very nature, leads us to err.

After the negative results of the body of the Transcendental Dialectic, in its Appendix Kant claims that reason, despite its liabilities, has a positive use: in particular, it systematizes and unifies our cognitions into a seamless whole. Kant thinks that such systematicity is the mark of *science*. Reason, in its search for cognitions that ground all others, demands that we discover the highest genera—concepts under which all others fall—and a parsimonious set of laws that ground our judgments. In this section, Kant again appeals to chemical examples (KrV, A645f./B673f.; A652f./B680f.), because chemistry is a paradigm systematic doctrine for him. Reason postulates its own ideas—those of the chemical elements—as the ultimate conditions for our chemical cognitions. Those ideas serve to systematize the science: they are the highest genera of chemistry and ground the science's explanations.

In KpV, to clarify his general notion of a law, which unifies the realms of nature and morality, Kant again references chemistry.

Even the rules of uniform appearances are called laws of nature (e.g., mechanical laws) only when they are either cognized really a priori or (as in the case of chemical laws) when it is assumed that they would be cognized a priori from objective grounds if our insight went deeper. (KpV, 5.26)

Certain laws of nature, including the fundamental laws of physics, are *a priori* for Kant. Chemical laws, by contrast, counterfactually *would* be cognized *a priori*, if our cognition

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<sup>2</sup> See KrV (Bxxxiii–xxxvii; A293–98/B349–55).



extended further. Although Kant means this passage to elucidate his conception of laws, without first understanding his views on of chemical and physical laws, the claim is obscure.

Chemistry is also discussed in the opening pages of MAN, where Kant presents his classificatory scheme for aggregates of the understanding's cognitions (concepts and judgments),<sup>3</sup> which I call 'the hierarchy of the sciences.' Subsequently Kant situates various sciences in this hierarchy, including physics, natural description, and chemistry. The taxonomy is described in the following passage (see Fig. 1).

Natural science would now be either *properly* or *improperly* so-called natural science, where the first treats its object wholly according to a priori principles, the second according to laws of experience. [¶] What can be called *proper* science is only that whose certainty is apodictic; cognition that can contain mere empirical certainty is only *knowledge* improperly so-called. Any whole of cognition that is systematic can, for this reason, already be called *science*, and, if the connection of cognition in this system is an interconnection of grounds and consequences, even *rational* science. If, however, the grounds or principles themselves are still in the end merely empirical, as in chemistry, for example, and the laws from which the given facts are explained through reason are mere laws of experience, then they carry with them no consciousness of their *necessity* (they are not apodictically certain), and thus the whole of cognition does not deserve the name of a science in the strict sense; chemistry should therefore be called a systematic art rather than a science. (MAN, 4.468)

At the most general level, there are *doctrines*; a doctrine is simply a collection of concepts and judgments. A *science* is a kind of doctrine whose cognitions are systematically interconnected. In a *rational science*, the cognitions of the science are linked as grounds and consequents. In the case that the ground-consequent relations of a science are grounded in experience, that science is merely *improper*, while if a rational science contains *a priori* ground-consequent relations, it is a *proper science*. In the above passage, Kant treats this condition on scientific propriety as equivalent with the condition that the science yields apodictically certain knowledge. Kant offers

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<sup>3</sup> The classificatory scheme that is described in the following applies only to *natural* doctrines. Kant, of course, believed that there are non-natural sciences such as metaphysics and logic.

a final, equivalent condition on propriety later in the preface to MAN: “I assert, however, that in any special doctrine of nature, there can be only as much *proper* science as there is *mathematics* therein” (MAN, 4.470). So there are three, apparently equivalent, conditions that a rational science must satisfy to be a proper science. A rational science is proper when it also (i) has *a priori* laws, (ii) yields apodictically certain cognitions, and (iii) allows for the application of mathematics.

Physics is the one and only proper natural science (MAN, 4.471), and the body of MAN is directed toward accounting for physics’ propriety. Conversely, natural history—the temporal ordering of natural phenomena—and natural description—the classification of natural phenomena according to similarities—are mere doctrines (MAN, 4.468). Though these ways of arranging natural knowledge clearly have a structure to them, they are not *systematic*, in the technical sense of the word, and hence are not sciences.

The science with the most interesting position in the architectonic of the sciences is chemistry.

So long, therefore, as there is still for chemical actions of matters on one another no concept to be discovered that can be constructed, that is, no law of the approach or withdrawal of the parts of matter can be specified according to which, perhaps in proportion to their density or the like, their motions and all the consequences thereof can be made intuitive and presented a priori in space (a demand that will only with great difficulty ever be fulfilled), then chemistry can be nothing more than a systematic art or experimental doctrine, but never a proper science, because its principles are merely empirical, and allow of no a priori presentation in intuition. Consequently, they do not in the least make the principles of chemical appearances conceivable with respect to their possibility, for they are not receptive to the application of mathematics. (MAN, 4.470f.)

Kant asserts that chemistry connects its cognitions as grounds and consequents, making it a *rational* science, but also that these connections are merely empirical, making it an *improper* science. Equivalently, Kant writes that chemistry inadequately allows for the application of

mathematics (see above). He thus prefers the designation of ‘systematic art’ or ‘experimental doctrine’ for chemistry.

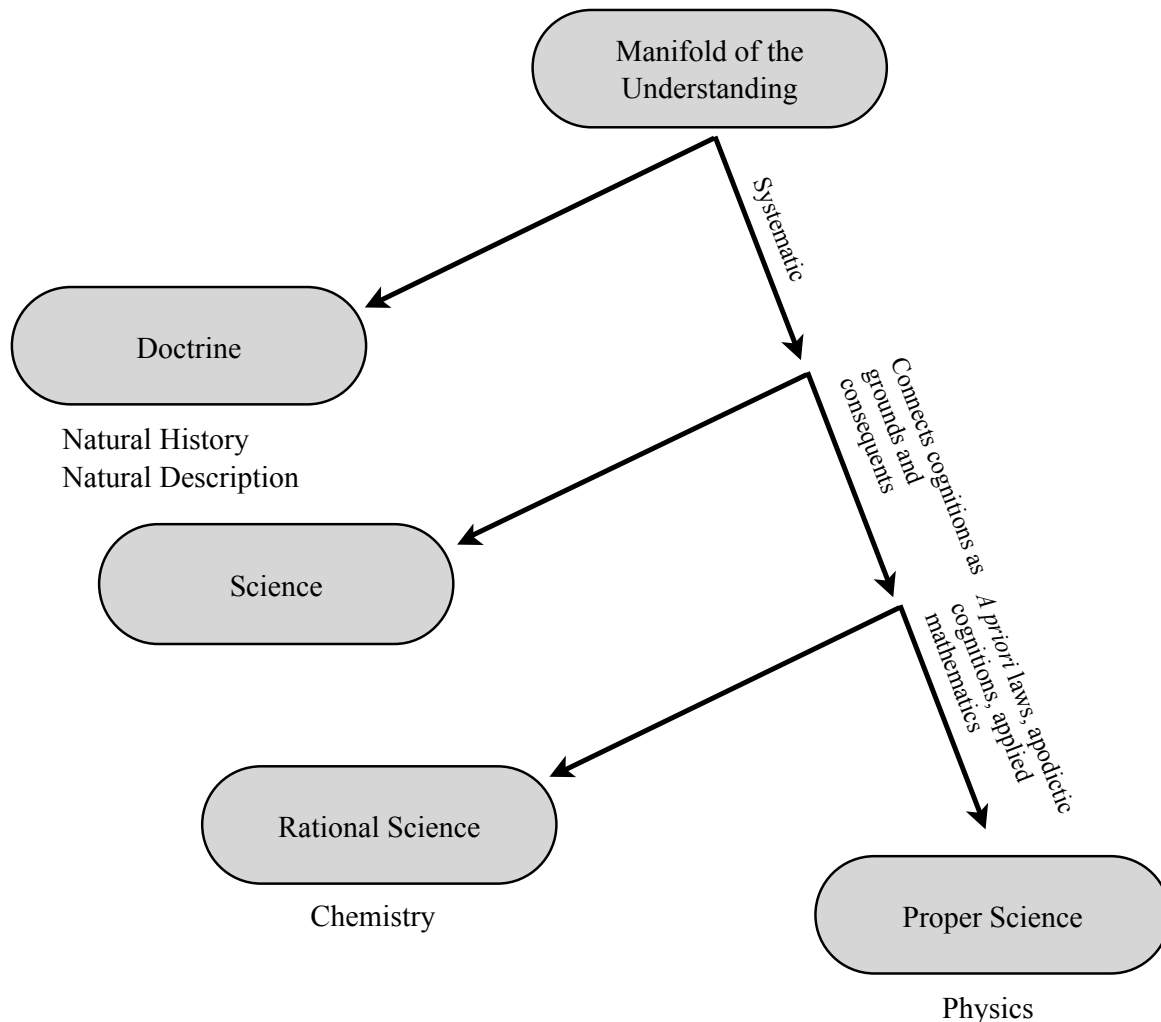


Figure 1: Species of Manifolds of the Understanding

Finally, in OP Kant provides his most in-depth consideration of chemistry. In this work, composed over the course of the late 1790s, Kant undertakes a transition (*Übergang*) from the metaphysical foundations of natural science to physics itself. In the course of this transition, Kant defends a modified theory of matter and discusses physical and chemical topics that received little consideration in MAN, including cohesion, density, states of aggregation, and the aether.

The conception of chemistry espoused in OP, in contrast to that defended in the Critical period,<sup>4</sup> integrates aspects of Antoine-Laurent Lavoisier's chemical revolution. For instance, Kant endorses Lavoisier's elements as well as his understanding of heat and combustion. Furthermore, the centerpieces of OP involve concepts of chemistry: to wit, Kant argues that the existence of the caloric can be deduced *a priori* and that the elements can be enumerated *a priori*. Concepts of chemistry and developments in late 18<sup>th</sup> century chemistry thus play crucial roles in Kant's last major work.

These references to chemistry throughout Kant's writings demonstrate the following. First, Kant was aware of developments in chemistry throughout the 1780s and 1790s. Second, Kant believes that consideration of chemistry clarified elements of his Critical philosophy (including the Copernican revolution, the positive use of reason, and his conception of laws). Third, Kant has a reasoned philosophy of chemistry. Although Kant discusses the status of chemistry in lesser detail than that of physics, it is clear, especially from his comments in MAN, that Kant has definitive, established views on the science.

Given chemistry's recurrence throughout Kant's corpus, a focused consideration of Kant's views on the science is in order: in this dissertation, I am concerned with three questions.

1. Why is chemistry improper?
2. Why is chemistry rational?
3. Does Kant continue to think chemistry to be improper, though rational, after his assimilation of Lavoisier's chemical revolution?

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<sup>4</sup> By "Critical period" I mean to refer to the *temporal* period in which Kant published his three *Kritiken*. Generally, I avoid use of the term "post-Critical period." While this locution has a legitimate use referring to the temporal period in which Kant composed his OP, it connotes that there is an opposition of thought between the *Kritiken* and OP. Since I do not endorse this connotation, I do not use this term.

Because of chemistry's intermediate status in the hierarchy of sciences, distinguishing it from the proper science of physics, on the one hand, and from mere sciences and natural description, on the other, clarifies the entire Kantian hierarchy of the sciences. Kant's conception of science is important to his Critical philosophy: Kant presents the Critical project as accounting for the possibility of a genuine *science* of metaphysics (KrV, Bvii–Bxliv; Prol, 4.255–64). Consequently, illuminating Kant's taxonomy of the sciences bears on one of his paramount philosophical claims. Moreover, an interpretation of chemistry's status sheds new light upon topics within Kant's theoretical philosophy. Chemistry is unique in being the only science described as rational, yet improper: it is a science despite the fact that, unlike pure physics, general metaphysics, and logic, it provides no a priori knowledge. Explaining the possibility of such an intermediate science requires a detailed inspection of the machinery of Kant's Critical system. For example, to make sense of chemistry's impropriety, one must first understand how mathematics can be applied in a natural science. This topic connects with Kant's doctrine of mathematical construction, which is crucial to the argument of the first *Kritik*. In fact, given Kant's idiosyncratic account of mathematical method, it is unclear how it is possible to apply mathematics in natural sciences, so in the course of clarifying chemistry's status, one must first elucidate mathematical construction and its function within natural science. In addition, as I mentioned above, Kant discusses chemical methodology in his consideration of the positive use of reason. Thus, explicating Kant's views on chemistry consequently clarifies this important—though difficult—doctrine of KrV.

Despite the utility of a study of Kant's conception of chemistry, outside of Carrier (1990, 2001) and Friedman (1992b, 2013), this topic has been largely passed over by contemporary scholars. Both have helpfully described parts of Kant's historical context—although I will argue

that Friedman focuses exclusively on only a fragment of this context in his recent treatment (2013: 234–58)—neither satisfactorily explains chemistry’s place on Kant’s hierarchy of the sciences or the possibility of chemical laws. In fact, Friedman explicitly *denies* the possibility of chemical laws, claiming that the science can achieve mere empirical regularities (1992a: 188–91, 2013: 241).<sup>5</sup> Scholars have failed to explain satisfactorily the possibility and nature of chemical laws and to interpret the important passage on laws from KpV. Authors that have written on the positive use of reason have, for the most part, overlooked the scientific context for Kant’s discussion of chemical ideas, e.g., Buchdahl (1966, 1971), Guyer (1990a, 2003), Morrison (1989), Rauscher (2011), and Wartenberg (1979, 1992). Few scholars have presented interpretations of the Kantian hierarchy of the sciences—including Plaass (1994), Pollok (2001), van den Berg (2011), and Watkins (1998)—but none adequately explains chemistry’s status in this hierarchy nor investigates the chemistry of Kant’s day. Furthermore, I argue that their interpretations ultimately fail because they *cannot* explain chemistry’s status. In contrast, more scholars have shown interest in Kant’s views on chemistry *after* MAN: particularly, in OP. Friedman investigates the extent to which developments in chemistry during the late 18<sup>th</sup> century influenced Kant to develop a new account of the science in OP (1992b: 264–90). This work is a point of departure for my dissertation, as Friedman fleshes out of the context for OP. As chemistry is central to the concerns of OP, consideration of the science arises in general works this text—such as Förster (2000) and Tuschling (1971). However, besides Friedman, only Dussort (1956) explicitly weighs in on the issue of chemistry’s propriety in OP. Dussort claims that chemistry becomes a proper science in OP, but I contend that his interpretation is inadequate. There is hence a gap in the current literature, one that this dissertation fills.

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<sup>5</sup> Allison (1994: 305) concurs that chemistry has no laws.

There are a few features that are characteristic of my methodology. First, my interpretation of Kant's views of chemistry is embedded in his historical context. I examine those sources to which Kant was exposed and based on which he would have claimed chemistry to be an improper science. Thus, before the main argument of the dissertation, I have included a prologue that introduces the reader to the state of chemistry in Kant's day. Second, I use my interpretation of Kant's views on chemistry to generate new understanding of other aspects of his philosophy of science, specifically, and his theoretical philosophy, generally. In the first two chapters, which concern Kant's Critical views on chemistry, I take his hierarchy of the sciences as a fixed point for my investigations: I hold fast to the hierarchy and determine how to incorporate it into Kant's broader philosophy. Then, in the third chapter, I determine, given Kant's modifications to his theory of natural science in OP, whether he would have re-evaluated chemistry's status.

In virtue of its topic and methodology, my dissertation fits into a recent body of literature in Kant scholarship, which seeks to clarify his philosophy of science and related issues in his theoretical philosophy by paying close attention to his historical context. In particular, recent scholars situate Kant's views with respect to mathematicians and natural philosophers to which he was exposed (and not *just* Newton). This approach is, of course, characteristic of Friedman's exemplary work, but recently others have also adopted it. For instance, the articles of the 2013 special section of *Studies in the History and Philosophy of Science* on philosophy of natural science from Newton to Kant all fall under the umbrella of this approach,<sup>6</sup> as do, for instance,

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<sup>6</sup> Especially Disalle (2013), Domski (2013), Dunlop (2013), Massimi and De Bianchi (2013), Smith (2013), Stan (2013), and Watkins (2013b).

Massimi (2011), Stan (2009, 2014), Vanzo (2012), and Warren (2010). The specific way in which my dissertation fits in this body of literature is discussed in detail in the conclusion.

In the body of the dissertation, I consecutively answer the three questions described above. In chapter 1, I explain why, given the state of chemistry at the time, Kant thought the science to be improper in the 1780s. I contend, *contra* the views of Körner (1955), Nayak and Sotnak (1995), and van den Berg (2011), that the application of mathematics to a science—which makes it proper—requires there be *a priori* laws of metaphysics that make possible the mathematical construction of the concepts of that science. In fact, the derivation of such laws for *physics* is one of the central goals of MAN, and Kant is pessimistic that the same sort of metaphysical foundation can be produced for chemistry. Kant considers two possibilities: either chemical explanations are mechanical—reducing to the shape and size of impenetrable corpuscles—or dynamical—reducing to the intensities of various fundamental forces. Neither possibility allows for the metaphysically valid application of mathematics to chemical interactions. The mechanical approach, for Kant, is metaphysically incoherent based on the principles of KrV. The dynamical approach, conversely, while metaphysically adequate and allowing for genuine chemical explanation, does not allow for the mathematical construction of chemical interactions. Thus, there is no metaphysically legitimate validation for the application of mathematics to the concepts of chemistry, making the science improper.

In chapter 2, I explain the sense in which chemistry is a rational science, that is, why chemistry “connects its cognitions as grounds and consequents.” I first clarify Kant’s conception of rational science, explaining that a science is rational insofar as it has genuine causal laws. I then describe the ground for chemical laws: the chemical elements. I explain that the elements, for Kant, are postulated by *reason* as the most basic bearers of chemical properties and the ideal



basis for all chemical phenomena. Subsequent to their postulation, we attempt to reduce and to unify all chemical phenomena under these elements via experimentation. My account of chemical laws reveals an important distinction between physical and chemical laws: whereas the laws of physics are grounded by the understanding, those of chemistry are grounded by reason. My interpretation hence clarifies the positive use of reason described by Kant in the Appendix to the Transcendental Dialectic of KrV: though reason cannot ground a *proper* science like the understanding, it nevertheless plays a crucial role in rational, natural science.

In chapter 3, I argue that, even though Kant makes significant changes to his theory of chemistry in OP, he continues to think of chemistry as an improper, though rational, science. In this chapter, I consider the most substantial modifications to Kant's views on chemistry. First, Kant adopts Lavoisier's antiphlogistic elements. Second, he contends that the existence of an omnipresent aether—which explains states of aggregation, cohesion, and the expression of forces—can be deduced *a priori*. Third, Kant holds that the elements can be enumerated *a priori*. I argue that, ultimately, these modifications would not have led Kant to reconsider chemistry's status. On the one hand, chemistry remains rational, for the elements continue to function similarly: they are basic bearers of properties and the fundamental causal, explanatory basis for the science. On the other hand, chemistry remains improper, because these changes do not make possible the sort of metaphysically validated, mathematical laws that are characteristic of proper science. Therefore, even after his assimilation of radically different views on chemistry, Kant held fast to the science's impropriety.

## PROLOGUE

### Chemistry in Kant's Day

Kant's views on chemistry are best understood in context. In this section I present aspects of the practice of chemistry in the 18<sup>th</sup> century that were known by and, I contend, important to Kant. As such, this section is not meant as an exhaustive depiction of 18<sup>th</sup> century chemical practice. Chemistry was thought of as an essentially practical or applied discipline by many during the early and middle 18<sup>th</sup> century. In particular, chemistry was commonly viewed as a worthwhile discipline only insofar as it studied processes that produce medicines, dyes, or metals. Thus, in chemical texts, authors commonly devote substantial tracts to the description of effective procedures for the production of such substances. For the most part, I pass over consideration of the fruits of practical chemistry, for Kant's views on chemistry have little to do with its application. His thesis that chemistry is an improper, but rational, science concerns the fundamentals of chemistry—its laws, explanations, elements, and methods—and not the particular analyzes and syntheses completed in laboratories of the day. Furthermore, as I am interested in *Kant's* chemical context, I focus on the chemists to whose work Kant was definitively exposed and whose contributions influenced his thought. Hence, significant figures of this century—such as Cavendish, Lemery, Macquer, Rouelle, and Scheele—receive little to no consideration, while focus is placed on generally lesser known authors—including Karsten, Wallerius, and Erxleben. This, of course, is not to discount the contributions of the chemists passed over. The following texts are those that bear on chemistry that Kant owned or likely read:

- Batsch (1789), owned by Kant (Warda 1922: 33).
- Boyle (1677), owned by Kant (Warda 1922: 33).

- Descartes (1650), owned by Kant (Warda 1922: 47).
- Erxleben (1772), owned by Kant (Warda 1922: 34) and used in association with Kant's 1776–1783 physics lectures.
- Erxleben (1787), used in association with Kant's 1787–8 physics lectures.
- Gehler (1787–95), mentioned throughout OP (21.162, 257, 303, 327, 339, 381; 22.212).<sup>7</sup>
- Girtanner (1792), owned by Kant (Warda 1922: 34).
- Hagen (1790), owned by Kant (Warda: 1922: 34).
- Hales (1748), owned by Kant (Warda 1922: 28).
- Karsten (1780), owned by Kant (Warda 1922: 34).
- Karsten (1783), used in association with Kant's 1785 physics lectures.
- Newton (1714), owned by Kant (Warda 1922: 35).
- Newton (1719), owned by Kant (Warda 1922: 35).
- Van Musschenbroek (1747), owned by Kant (Warda 1922: 35).
- Wallerius (1761), owned by Kant (Warda 1922: 36).

In this prologue, I present some of the key aspects of chemical practice that Kant gleaned from these sources. This presentation proceeds as follows. In section 1, I describe the different views on the nature of chemistry: its object, its ends, and its methods. Then I examine the various approaches to chemical explanation in section 2. In the course of this discussion, I consider different conceptions of the elements in the 18<sup>th</sup> century. Lastly, in section 3, I describe prominent chemical developments that occurred in Kant's lifetime, which culminate in Lavoisier's chemical revolution.

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<sup>7</sup> See Kant (1993: 260n.).

## 1. The Nature of Chemistry

As I mentioned above, many conceived of chemistry as an essentially practical science that aims at the production of medicinal agents in particular. This conception of chemistry was popularized by Paracelsian iatrochemistry and furthered by van Helmont in the 16<sup>th</sup> and 17<sup>th</sup> centuries. Subsequently, luminaries such as Boyle and Boerhaave contended that chemistry was no mere handmaiden for apothecary: rather, it is a science in its own right.<sup>8</sup> By Kant's day, the independence of chemistry as a science is broadly accepted;<sup>9</sup> moreover, chemists of the 18<sup>th</sup> century generally agree on the essence of the science.

For many chemists of the early modern period, chemistry is fundamentally the study of the synthesis and analysis of material bodies. Stahl claims that “Universal Chemistry is the Art of resolving *mixt, compound, or aggregate* Bodies into their *Principles*; and of composing *such Bodies* from those *Principles*” (1730: 1), where principles are simple and the “first material causes of *Mixts*” (1730: 3). Erxleben claims that chemistry consists of the decomposition of bodies into simpler parts (diathesis) and the combining the simpler parts (synthesis) (1775: 5f.). Wallerius divides the “systematic art” of chemistry into a pure and an applied part. Whereas the latter aims at effective production of useful materials, the former, pure part of chemistry “is a science which deals with the mixing of bodies and their originations” (1761: 1). Karsten explains that, “What one calls chymistry or chemistry, properly consists in a complete instruction of the actual development of the material of nature, when one either separates the simpler, inhomogeneous elements from each other, or, through alternative combination of such simple

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<sup>8</sup> In the preface to his *Skeptical Chymist*, Boyle contends that chemical experimentation may have important implications for physics and philosophy (2003: 1–10). Powers (2012) describes how Boerhaave's pedagogical aims and methods related to his views on chemistry being a genuine, distinct science.

<sup>9</sup> Erxleben (1775), for instance, defends the idea that chemistry is an independent science while lamenting that, under the name of chemistry, students have previously only learned the pharmaceutical arts.

inhomogeneous materials, bring forth new products” (AKN, 29.193). And Hagen claims that, “The end of chemistry (*Chemia*) is knowledge of the mixture or the constitution, relationship, and combination of the constituent parts of each and every body” (1790: 1).<sup>10</sup> The predominance of 18<sup>th</sup> century chemists thought of the science as primarily studying the relationship between simple substances and the composite substances that the former compose. As can be gleaned from these passages, this project divides into studies of analysis and synthesis. In fact, chemistry was classically known in Germany as *Scheidekunst*, which literally translates as the art of division or analysis.<sup>11</sup> Although in the time period under consideration, the name *Chemie* becomes more popular in Germany, the thought that chemistry is essentially the science of the analysis and synthesis is retained.

Karsten defends a somewhat more restricted vision of chemistry, claiming that the science is the *merely practical* doctrine of the analysis and synthesis of substances. (AKN, 29.193f.). Knowledge of the elements and of the processes that underlie chemical behavior belongs not to this practical discipline, but to *physics*. In his *Elementa Chemiae*, Boerhaave similarly conceives of chemistry as an art or practical discipline: “Chymistry is an art shewing how to change bodies by proper instruments, that their effects, and the causes from these effects, may be known” (Boerhaave 1732: 12).

## 2. Chemical Explanation and Elements

The theoretical goal of early modern chemistry is the explanation of chemical phenomena—the analysis and synthesis of substances—especially by means of *elements*. That

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<sup>10</sup> See also Hagen (1790: 2–4).

<sup>11</sup> Kant recognizes this historical name for chemistry and conceives of the science in terms of synthesis and analysis (DP, 29.117).

said, in this epoch there are conflicts regarding the nature of explanation and of elements. Views on explanation and those on the elements each admit of division into two classes. As Kant describes, chemical explanations may be dynamic—according to which the fundamental grounds of explanation are forces—or mechanical—according to which the fundamental grounds of explanation are the motions and impacts of impenetrable corpuscles.<sup>12</sup> During this period, there are two influential views on the nature of the elements: the power conception and the operationalist conception. Both views concur that elements are the simplest chemical substances; they disagree, however, on the organizational role of the elements. According to the power conception, elements are fundamentally bearers of particular powers, and thus the elements serve as the ultimate ground for the explanation of chemical phenomena. The operationalist conception, conversely, conceives of elements merely as those simple substances that do not admit of further analysis. In this section, I discuss, respectively, approaches to explanation and conceptions of the elements.

## 2.1. Explanation

According mechanical approach, all explanations reduce to the motions of absolutely impenetrable corpuscles. The mechanical approach to natural philosophy was widespread in the 17<sup>th</sup> and 18<sup>th</sup> centuries and was endorsed by figures such as René Descartes and Robert Boyle.

For Descartes, matter is essentially passive, governed by three laws of motion (1983: 59–62). There are three tiers of Cartesian material ontology: the three corresponding types of matter are differentiated in terms of the size of their impenetrable parts (Descartes 1983: 110). The

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<sup>12</sup> Kant makes this distinction in MAN (4.524f.). His views on these different modes of explanation are discussed in chapter 1.

third, earthy type is the bulkiest sort of matter: its pores and interstitial spaces are filled with the rarer matters of the first and second type. Parts of matter cause motion through impact, and the diversity of the shapes of these constituent parts explain the variety of behaviors of bodies. The exemplar for the Cartesian approach to natural philosophic explanation is his description of the activity of the magnet (Descartes 1983: 242ff.). According to Descartes, the magnet attracts metal not through some invisible, occult force, but through the impact of corpuscles. A magnet emits minuscule, screw-like, and grooved particles that form a vortex around it. Metals, conversely, have two sorts of pores: those that allow the entry of one sort of grooved particle and those that allow for the entry of the other, mirror-image grooved particle. Depending upon the orientation of a metal *vis-à-vis* the magnet, the grooved particles may push the metal away or draw it closer by passing through its pores.

Boyle concurred that phenomena ought to be explained by appeal to the shape, size, and impact of matter.

Thus the universe being once framed by God, and the laws of motion settled and all upheld by his perpetual concourse and general providence, the [corpuscular or mechanical] philosophy teaches that the phenomena of the world are physically produced by the mechanical properties of the parts of matter, and that they operate upon one another according to mechanical laws. (Boyle 2003: 262f.)

Boyle especially argues for his mechanical philosophy to replace both Aristotelian approaches to material explanation as well as the *tria prima* of the Paracelsians.<sup>13</sup> But whereas Descartes (1983: 46f.) contends that the universe is a plenum—it is entirely filled with matter—Boyle

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<sup>13</sup> Paracelsus advanced the idea that all substances are made up of sulphur, salt, and mercury—the *tria prima*. He put this theory to great use by liberally inferring from analogies between these three principles and other topics (e.g. the holy trinity).

entertains the possibility of the vacuum in virtue of his air pump experiments.<sup>14</sup> Indeed, the possibility of the vacuum was a common topic of contention amongst mechanists.

Johann Lambert, with whose work Kant was well acquainted, also defended a mechanical approach to natural explanation.<sup>15</sup> According to Lambert, from the very idea of an existent in space, we can derive the fact that it must exclude all other existents in its space. That is, the impenetrability of matter follows from its very existence in space.<sup>16</sup> Changes of motion, for Lambert, are caused by the immediate contact of impenetrable matter with other impenetrable matter. As Friedman (2013: 122) explains, Lambert was inspired by the metaphysical methods of Leibniz and Wolff. In particular, he thought that the foundations of natural philosophy ought to be grounded on the analysis of concepts, like those of solidity, moving force, and existence. Lambert thus thinks of himself as giving the appropriate—Leibnizian-Wolffian—metaphysical foundations for mechanical philosophy.

Erxleben espouses a mechanical approach to chemical explanation, exemplifying the approach with a mechanical description of the dissolution of a salt by water (1772: 168–70).<sup>17</sup> When a salt is immersed in water, the corpuscles (*Teilchen*) of the water enter the pores of the salt and separate them. The corpuscles of the salt are then separated from each other by the interstitial water. As the parts of the salt have been separated, it has been dissolved, though it still

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<sup>14</sup> See Partington (1961–70: 2.517ff.) and Shapin and Schaffer (2011) for more on Boyle’s air pump experiments and their influence.

<sup>15</sup> Friedman (2013: 126f.), Plaass (1965: 22), and Warren (2001a: 99–110) contend that Lambert is the target of Kant’s polemics against the “mathematical-mechanical” mode of explanation in MAN (4.497f., 524f.).

<sup>16</sup> For an extremely clear and interesting description of Lambert’s views on matter *vis-à-vis* Kant’s, see Friedman (2013: 121–30).

<sup>17</sup> See also Erxleben (1775: 66f.).



has effects (e.g., a salty taste). A similar understanding of dissolution is found in Wallerius (1761: 161).<sup>18</sup>

In opposition to the mechanical approach to explanation is the dynamical, popularized by a certain brand of Newtonian. In the preface to the first edition of his *Philosophiae Naturalis Principia Mathematica*, Newton writes the following.

[... T]he basic problem of philosophy seems to be to discover the forces of nature from the phenomena of motions and then to demonstrate the other phenomena from these forces. [...] If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning! For many things lead me to have a suspicion that all phenomena may depend on certain forces by which the particles of bodies, by causes yet known, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede. (Newton, 1999: 382f.)

According to the Newtonian approach, we deduce the existence of forces (like that of gravitation) as the causes of observable phenomena. In this passage, Newton suggests that there may be other, short-range forces that explain phenomena such as cohesion and repulsion, though he laments that these forces cannot be treated according to the mechanical principles of the *Principia*. This approach arises again in the last paragraph of the General Scholium, but is discussed in greatest detail in the famous 31<sup>st</sup> Query of his *Opticks* (Newton 1730: 350–382).<sup>19</sup>

Newton begins this Query by asking the following rhetorical question.

Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting and inflecting them, but also upon one another for producing a great Part of the Phænomena of Nature? (Newton 1730: 350)

Afterward, Newton goes on to suggest force-based explanations for a variety of phenomena, including particular cases of chemical reaction. For example, Newton describes the dissolution of

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<sup>18</sup> For more on the mechanical approach to chemical explanation, see Ihde (1964: 25–9)

<sup>19</sup> Newton was quite interested in chemistry (Partington, 1961–70: 2.468–485). His chemical theory, especially as expressed in *De nature acidorum* was profoundly influenced by famous (al)chemist, van Helmont (Newman 2008).

iron filings in *aqua fortis* by means of such forces. According to his understanding, the short-range force of attraction between the metal and the acid is so strong that the parts of the acid “rush towards the Parts of the Metal with violence” (1730: 352). Indeed, the accelerative attraction is so great as to produce sensible heat and that the parts of the acid force their way between the parts of the iron, separating them, effecting a dissolution of the metal into the liquid. Furthermore, that the acid and iron cannot easily be separated is, for Newton, evidence of the powerful attractive force between the two. For the dynamical approach there is no need for the mechanical hypotheses of different sorts and sizes of elementary material particles. Newton and the dynamists avoid postulating hooks and sharp edges on corpuscles to explain chemical dissolution and decomposition (1730: 375–9).<sup>20</sup> As Kant explains the distinction, according to dynamism, forces cause motions of bodies, whereas, according to mechanism, motions (and impacts) of (absolutely impenetrable) bodies cause forces (V-Met/Dohna, 28.664f.).

This dynamic approach was extremely influential amongst chemists in the 18<sup>th</sup> century.<sup>21</sup> Geoffroy’s (1718) important work on chemical affinities, as Thackray (1970: 90) explains, was inspired by Newton’s dynamical program for chemical attractions described in his 31<sup>st</sup> Query. In this work, Geoffroy provides an idiosyncratic symbolism for chemical substances along with table that represents and ranks the various affinities or attractions amongst these substances. So, for instance, Geoffroy’s table of affinities represents that metallic substances have affinity for both nitric acid and sulphuric acid, though they each have a greater affinity for sulphuric acid. Discussion of this Newtonian approach is also found in, for example, the work of Karsten (AKN,

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<sup>20</sup> Newton also objects to mechanical explanations as circular (Newton 1730: 363f.). Stahl has similar reservations about mechanism, see Carrier (2001: 222f.).

<sup>21</sup> For a superb discussion of this influence, see Thackray (1970).

29.293), who conceives of chemical affinity as a strong attraction between the elementary particles of inhomogeneous substances.

Another prominent product of the Newtonian, dynamical approach was Boscovich's theory (1763). Boscovich thought that matter was uniformly homogeneous: that is, every (point-like) unit of matter is identical to every other. Furthermore, there is only *one* active force emitted from matter. The specific variety of matter and the observable attractive and repulsive forces are explained by the claim that the active material force varies its intensity and alternates between attraction and repulsion at different distances. At great distances, the active force of matter is attractive, and its intensity is measured by an inverse-square law. At nearer distances, the material force is repulsive, explaining the relative impenetrability of matter. At intermediate distances, the force may be attractive or repulsive (Thackray 1970: 150–5).

## 2.2. Elements

Chemical explanation in the 17<sup>th</sup> and 18<sup>th</sup> centuries was connected with conceptions of the elements. As I mentioned above, Boyle advances his corpuscular philosophy against modes of chemical explanation popular in the day. In particular, he objects to the postulation of hypostatical principles as the basis for chemical explanation. According to this conception of the elements, which I call the 'power conception,' elements or principles are fundamentally bearers of particular properties, and chemical explanation aims at the reduction of observed phenomena to these principles. Many chemists in this time period accept a list of elements that was a subset of the union of the Aristotelian elements—earth, air, fire, water—and Paracelsus' *tria prima*—salt, sulphur, and mercury. So where Boyle argues that there are truly only two principles of explanation—matter and motion—many chemists of his day accepted more abstract principles.

Despite Boyle's efforts, this power conception of the elements remains popular, especially on the continent. The approach finds a prominent success with the work of Georg Stahl. For Stahl, chemistry is the "art of resolving compounds into their principles," where principles are the simple material causes of mixts (Stahl 1730: 1, 3). He then proceeds to differentiate two concepts thereof. According to the *a priori* conception of principles, they are the simple substances that pre-existed in the mixt, whereas according to the *a posteriori* conception, they are those simple substances into which we last resolve materials (Stahl 1730: 4). Stahl is skeptical of the *a posteriori* approach, as we cannot possibly isolate principles in their purity. Rather, we must postulate these principles prior to inquiry and reduce chemical phenomena thereto.

Stahl's theorizing and experimentation regarding the principle of inflammability are particularly noteworthy. Stahl was influenced by J. J. Becher, who believed inorganic substances to be made up of three earthy principles: *terra pinguis* (sulphur), *terra mercurialis* (mercury), and *terra lapida* (salt). Each of these types of earth explains some of the properties of inorganic substances. *Terra pinguis* is of most interest: its presence in an inorganic substance explains that substance's burnability. So, for instance, limestone when heated becomes quicklime, a crystalline substance with different chemical properties from the original limestone (this is an instance of the process called *calcination*).<sup>22</sup> That the limestone undergoes this reaction when heated is explained by the presence *terra pinguis*. Once this *terra pinguis* is expelled from the limestone during calcination, its chemical properties change, leaving a distinct substance, quicklime (Ihde 1964: 29).

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<sup>22</sup> Generally, calcination is the process where by an inorganic substance is heated below its melting point until an ash-like 'calx' is produced. The calx has different chemical properties from the original substance: for instance, a metallic calx lacks the malleability and luster of the metal.

Stahl adapted Becher's theory of inorganic substances, renaming *terra pinguis* 'phlogiston' and expanding the theory. Stahl's phlogistic theory held that the principle of calcinability—that which explains the burnability of inorganic substances—is, identically, the principle of combustibility—that which explains the burnability of organic substances. His influential and striking claim is that phlogiston (the sulphuric principle) explains inflammability behavior in the animal, vegetable, mineral, and metallic kingdoms (Stahl 1734: 36). He claims to have proven this fact through his most famous experiment (Stahl 1734: 119f.), which began with the calcination of metallic lead to produce lead calx. According to Stahl's theory, the lead is calcinable because it contains phlogiston. During the calcination, the lead's phlogiston is expelled, leaving lead calx, a powdery substance with distinct appearance and chemical reactivities; these changes are due to the calx's being dephlogisticated. Subsequently Stahl mixes the lead calx with charcoal. After then heating the mixture, Stahl finds that a sample of metallic lead *revivified* with its characteristic properties. This experiment shows that whatever was lost by the metal during calcination was replaced during the combustion of the charcoal. Since phlogiston was expelled from the lead during calcination, the combustion of the charcoal must have emitted free phlogiston that was absorbed by the lead calx, thus producing the sample of metallic lead. Therefore, both calcination and combustion are phlogistic processes.<sup>23</sup>

Stahl's experiment is demonstrative of the methodology of many chemists in the 18<sup>th</sup> century. Whereas mechanical philosophers explain chemical behavior by postulating shapes and sizes of parts of matter—e.g, explaining magnetic attraction through grooved particles or dissolution through sharp particles—those that endorse the power conception seek primarily to reduce chemical phenomena to the behavior of the elements. Each of these elements is either a

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<sup>23</sup> For more on Stahl's phlogistic theory of chemistry, see Partington (1961–70: 2.665ff.).

bearer of a property or something that makes possible the manifestation or expression of that property. So, for instance, many chemists think phlogiston or fire to be an *instrument* insofar as causes modifications to substances, though they recognize that these modifications require the presence of air. Thus air, another element, is assumed to be a *vehicle* for phlogiston or fire.<sup>24</sup>

Although Stahl endorses an elemental, dynamical approach to explanation, he nonetheless also accepts the existence and the ultimate fundamentality of corpuscles.<sup>25</sup> As the elemental-power approach to explanation is opposed to the mechanical approach of postulating shapes and sizes of corpuscles, there hence appears to be tension in Stahl's views.<sup>26</sup> Carrier helpfully dissolves this tension by arguing that Stahl's corpuscularism is an *ontological* thesis, while he believes chemical *explanations* to rest on the nature of the elements (2001: 223). Although there may appear to be mismatch between his ontology and explanatory framework, Carrier's resolution at least removes the appearance of bald self-contradiction.

I should note that there is an affinity, but *not* identity between the dynamic approach to explanation and the power conception of elements. Newton, for example, accepted the dynamic approach to explanation, but believed that physical explanation requires only a single, homogeneous sort of matter and not a variety of differently powered elemental sorts (as did Boscovich, although in a different way). The corpuscles of this one type of matter may combine together to form a variety of different shaped aggregates. Based on the differences in the shapes of these sorts of aggregates, they each have different properties (Thackray 1970: 161–198). These different sorts of collections of homogeneous particles will have different (intensities of)

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<sup>24</sup> Gehler describes elements largely along these same lines: chemists began with the Aristotelian elements and have added to this list only a few more, including phlogiston, aether, and magnetic matter (1787–95: 1.832f.).

<sup>25</sup> For more on Stahl's complicated theory of principles and composites, see Partington (1961–70: 2.664f.).

<sup>26</sup> Stahl was fiercely opposed to mechanical explanations (Partington 1961–70: 2.665).

short-range forces, thus serving as the basis for chemical explanation. For Newton (and some of his followers), natural phenomena are hence explicable dynamically regardless of the homogeneity of matter.

In addition to proposing that matter and motion are the fundamental agents of physical explanation, Boyle also introduces a new conception of the elements. According to Boyle, elements are not presupposed as those fundamental principles or powers present in all substances. His *Skeptical Chemist* contains a sustained refutation of the Paracelsian and Helmontian conceptions of the elements (Boyle 2003). Rather, Boyle claims, under the guise of his mouthpiece, Carneades, that “I now mean by Elements, as those Chymists that speak plainest do by the Principles, certain Primitive and Simple, or perfectly unmingled bodies; which not being made up of any other bodies, or of one another, are the Ingredients of which all those call’d perfectly mixed Bodies are immediately compounded, and into which they are ultimately resolved: now whether there be any one such body to be constantly met with in all, and each, of those that are said to be Elemented bodies, is the thing I now question” (2003: 350). *Contra* those defenders of the power conception of elements, Boyle argues that we cannot, in advance of inquiry, set out a list of elements as the explanatory/causal foundation of chemistry. Rather, we ought call elements only those substances that we can isolate in the laboratory and cannot further decompose. The chemist cannot set out these elements in advance of inquiry, for she can only discover those substances that cannot be decomposed through *experiments*. This notion of elements I call the *operationalist* conception, following Carrier (2001).

During the 18<sup>th</sup> century, the power conception remains popular. Many chemists continue to admit only a small number of elements and conceive of them as bearers of powers. However, as I explain below, the operationalist conception is at the heart of Lavoisier’s chemical

revolution, leading to an enshrinement of this approach and a substantial expansion in the accepted lists of elements.

### 3. 18<sup>th</sup> Century Developments

#### 3.1. Pneumatic Chemistry

In the 18<sup>th</sup> century, a group of chemists, especially British chemists, were concerned with studying the chemical properties of air and simultaneously emphasized the use of meticulous, quantitative measurements. Boyle's air pump experiments, which allowed him to investigate the causal powers of air, were decisive for the rise of this *pneumatic* chemistry. In particular, Boyle's experiments—including those involving the Torricellian barometer—led him to argue that air has a “spring” (or pressure), analogizing air's corpuscles with tiny springs. Boyle also experimented with different kinds of airs trapped in glass chambers (Partington, 1961–70: 2.523ff.), although it was only later in the development of pneumatic chemistry that scientists recognized that these different sorts of air had different chemical properties. Prior to pneumatic chemistry, many chemists thought air to be a *passive* substance, serving only as a vehicle for the transport of other materials. Boyle's air pump experiments are the first in a long series that demonstrate air to be active and to come in various kinds.

Another central figure of this approach was Stephen Hales, a figure well known to Kant.<sup>27</sup> Hales espouses the so-called “statical way of inquiry” (1738: ii), which emphasizes experimentation and the use of precise quantitative measurements. Hales thought this approach

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<sup>27</sup> In addition to owning a German translation of *Vegetable Staticks*, Kant also regularly cites Hales in his pre-Critical works. See FEV (1.208), NTH (1.326), DI (1.381), and GNVE (1.457).



to have facilitated recent progress in research on animals and sought to facilitate a similar progress in research on plants (1738: i, 2f.).

And since we are assure that the all-wise Creator has observed the most exact proportions, *of number, weight and measure*, in the make of all things; the most likely way therefore, to get any insight into the nature of those parts of the creation which come within our observation, must in all reason be to number, weigh and measure. And we have much encouragement to pursue this method, of searching into the nature of things, from the great success that has attended to any attempts of this kind (1738: 1f.)

Under the influence of Boyle, Hales, and other pneumatic chemists, certain sorts of quantitative methods are common in chemistry by the mid-18<sup>th</sup> century. Amongst some chemists, the careful weighing of reagents and products was commonplace. Boyle, for example, was aware that metals gain weight during calcination, explaining that during the process, metals must gain subtle “igneous corpuscles” (Ihde 1964: 29).<sup>28</sup> Boyle also determined specific gravities of various solids and liquids (Partington 1961–70: 2.512).

In chapter V of *Vegetable Staticks*, Hales is especially concerned to demonstrate via experiments that “*a considerable quantity of air is inspired by Plants*” (1738: 155). In the subsequent pages, Hales describes his careful measurements of the quantity of air imbibed by various plants through their various parts (bark, leaves, roots, etc.). He emphasizes that air is *chemically active* and combines with other substances (especially with plants and animals). These researches give rise to a deeper investigation into the nature of air in chapter VI of the text (1738: 162–318). Therein Hales is especially interested to capture and to examine the gases produced by heated substances. To this end he utilizes a variety of chemical apparatuses, including the pneumatic trough, which is a crucial technology for pneumatic researches of the

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<sup>28</sup> Stahl was aware of weight gain during calcination, but did not appear to think it demanding of explanation (Partington 1961–70: 2.675–8).

century. The pneumatic trough allows the chemist to purify and to isolate gases emitted from chemical reactions. Although Hales uses the pneumatic trough to collect gases and to measure their quantities, he fails to pay attention to the different chemical qualities of the isolated gases (Ihde 1964: 34).

Hales is an exemplar, in method, precision, and topic, of the pneumatic approach to chemistry.<sup>29</sup> Along with Hales, other luminaries such as Joseph Black, Henry Cavendish, and Joseph Priestley, examine the chemical character of air while emphasizing exact quantitative measurements. While Stahl and others—like van Helmont, Boyle, and Boerhaave (Ihde 1964: 32; Powers 2012: 156f.)—think of air as an element and as a mere instrument or vehicle for chemical reactions, the pneumatic chemists discover that there are multiple kinds of air and that they each have their own chemical reactivities. The preeminent discovery of this period is Joseph Black's isolation of a gas, called *fixed air*, emitted during the calcination of magnesia alba (Black 1754). This fixed air, now known as carbon dioxide, has different chemical properties from atmospheric air. Black's discovery was historically crucial for the reevaluation of the elemental status of air. Soon thereafter, others of the pneumatic school discover other species of gases, including inflammable air (hydrogen gas) by Cavendish in 1766, noxious air (nitrogen gas) by Rutherford in 1772, and dephlogisticated air (oxygen gas) by Priestley in 1774 (Ihde 1964: 32–54). Gehler is one of the German sources known by Kant who claims that, in virtue of these developments, “air” cannot be the name of an element. Rather, it is a general term that refers to a wide variety of elastic fluids (Gehler 1787–95: 1.833). Kant eventually echoes this sentiment (DP, 29.162).

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<sup>29</sup> Credit for the rise of pneumatic chemistry ought also be shared with van Helmont and Boyle, who also researched the effects of air. But as Ihde notes, “Although such investigators as van Helmont and Boyle made a certain amount of progress in the study of gases, they failed to establish a continuing tradition for several reasons” (1964: 32).

Some chemists of the time period seek to integrate these developments into the phlogistic framework for chemistry. In the second volume of his *Experiments and Observations on Different Kinds of Air*, Priestley announces his discovery of dephlogisticated air (1775b). Therein he opposes the “maxim” that air is a “*simple elementary substance*,” contending that different airs—expressing different chemical or physical properties—may be more or less saturated with phlogiston. Common air may be saturated with phlogiston (it may be *phlogisticated*) through animal respiration or combustion, while “agitation in water” or plants may purify such phlogisticated air to its original state (Priestley 1775b: 30f.). Rutherford’s noxious air, which cannot support combustion or animal respiration, is thought by Priestley to be maximally saturated with phlogiston. In August of 1774, upon heating *mercurius calcinatus per se* (mercuric oxide, the result of calcining mercury), Priestley discovers that there is air that is even purer—contains less phlogiston—than common air. Priestley finds that the gas captured from this process supports the combustion of a burning candle better and longer than common air (Priestley 1775b: 42). Furthermore, he observes that a mouse lives longer when encased in a chamber filled with this gas than one filled with common air (Priestley 1775b: 43–7). Combustion and respiration, for Priestley, are phlogistic processes: during either, phlogiston must be emitted. He thinks that, in the case that the ambient surroundings can take in no phlogiston, such phlogistic processes must halt. Since the new gas supports these processes for longer than any other type of air, it must contain a minimal amount of phlogiston. On the basis of this understanding, Priestley thus names the gas “dephlogisticated air.” Priestley also conceptualizes the discoveries of other airs within the phlogistic framework, thinking of Cavendish’s inflammable air, in virtue of its combustibility, as “loaded with phlogiston” (1775a: 65), or as a combination of an acid vapor with phlogiston (1775b: 31f.). Others, like Scheele and

Kirwan, think of inflammable air as identical to phlogiston, in virtue of its combustibility (Ihde 1964: 40). Karsten covers many of the developments in theories of gases and their connection to phlogistic theory and theories of heat (AKN, 29.509–25), and Kant demonstrates his own exposure to the discovery of different sorts of air in DP (29.162f.).

In addition, pneumatic chemists developed new sorts of measurements. For example, Priestley's experiments on nitrous air (NO) gave rise to eudiometry—the measuring of the quality of air. In the first volume of his *Experiments and Observations on Different Kinds of Air*, Priestley describes the newly captured nitrous air and its various qualities. He finds that nitrous air reacts with common air to form a red-orange gas (1775a: 110f.), which dissolves in water. This reaction leads to a diminution in volume: one volume of nitrous air will react with two volumes of common air to leave 1.8 volumes of residual gas, at which point, the residual gas will no longer react with nitrous air. This diminution of area, however, is characteristic only of the reaction between nitrous air and respirable air. If two volumes of air spoiled by combustion or respiration are combined with a volume of nitrous air, the residual gas will be greater than 1.8 volumes. On the basis of his experiments, Priestley concludes that the degree to which the air is not fit for respiration or combustion is measured by the residual volume after its reaction with nitrous air. Hence, he argues that that the volume of the residual gas after combining an air with nitrous air is a measure of the quality, or respirability, of the air. According to Priestley, this constitutes a more accurate and reliable measure of quality of air than the amount of time that it supports combustion or respiration (1775a: 114f.). With these claims, Priestley thus develops the first proper test of eudiometry.<sup>30</sup> Upon subjecting his dephlogisticated air to this 'goodness of

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<sup>30</sup> Nitrous air (NO) combines with the oxygen gas (O<sub>2</sub>) in common air to produce red-orange dephlogisticated nitrous air (NO<sub>2</sub>). The dephlogisticated nitrous air dissolves in water, however leaving a residual gas of smaller

air' test, Priestley finds that it can combine with much more nitrous air per volume than common air, further convincing him of the quality—and dephlogisticatedness—of this air (1775b: 47f.).

The developments of pneumatic chemistry—both its results (the isolation and experimentation with different types of air) and its methods (new instrumentation and emphasis on quantitative measurement)—find expression in German sources from the time period. Karsten's AKN, in particular, covers many of these developments. In the V<sup>th</sup> Division of this work, Karsten covers experiments regarding pressure conducted with the air pump (AKN, 29.217–227) and includes a discussion of the barometer (AKN, 29.218). Erxleben similarly discusses air pump experiments (1772: 190–7) and the barometer (1772: 211–8). Throughout the XVI<sup>th</sup> Division, Karsten discusses the different kinds of air that can be produced by chemists, including phlogisticated air (AKN, 29.232), flammable air (AKN, 29.342), hepatic air (AKN, 29.343), saltpeter air (AKN, 29.344), Scheele's fire air (AKN, 29.345), and Priestley's dephlogisticated air (or elementary air) (AKN, 29.346). Furthermore, Karsten discusses the variety of measurement devices utilized in chemistry and lists various measurements determined by chemists, demonstrating acquaintance with the pneumatic chemist's emphasis on measurement. For instance, at one point, Karsten produces a table describing the amounts of water (boiling and at room temperature) required to dissolve a given quantity of various salts and follows this table with a list of the specific weights of various acids and gases (amongst other quantitative measures) (AKN, 29.313ff.). In the XII<sup>th</sup> division, Karsten lists the specific weights of various airs (AKN, 29.357). He also mentions the use of various measuring devices in chemistry, including the thermometer (and relevant temperature scales), the aerometer, the

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volume: see Ihde (1964: 47n.). Priestley's quality of air measurement thus determines the relative proportion of oxygen in a gaseous mixture.

barometer, the pyrometer (AKN, 29.199–203), and the eudiometer (AKN, 29.344f., 358f.). A more extensive list of specific weights, attributed to Musschenbroek, can be found in Erxleben (1772: 161–6).

### 3.2. Theories of Heat

A number of notable developments in the science of heat occur in the 18<sup>th</sup> century. Boerhaave contends that fire has historically attracted the attention of chemists but demands that they only infer about the nature of fire *from experiments* (Boerhaave 1732: 33).<sup>31</sup> From such experiments Boerhaave concludes that heat has the power to expand substances, including air, making possible the measurement of heat with thermometers (especially Drebbel's and Fahrenheit's) (1732: 35ff.). Such thermometers Boerhaave puts to good use in a bevy of experiments on heat, on the basis of which he contends that inflammability phenomena rest on the *pabulum ignis*, the fuel for fire in combustible substances (1732: 68ff.).<sup>32</sup> Fire, for Boerhaave is a chemical *instrument* (1732: 33), such instruments are the tools of chemical analysis. Through (and only through) interaction with such instruments (fire, air, water, earth, menstrua) could the chemist discover the “latent properties of chemical species” (Powers 2012: 72). The instrument of fire, according to Boerhaave, causes not only visible flames, but all thermal phenomena (1732: 34).<sup>33</sup>

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<sup>31</sup> Experimentation was common in chemistry before Lavoisier. Hales, Stahl, Boyle, Newton and others all recognized its importance.

<sup>32</sup> For a discussion of Boerhaave's views on the *pabulum ignis* and its relation to Stahl's phlogiston, see Powers (2012: 158–163).

<sup>33</sup> Massimi (2011) does an admirable job of tracing the influence of Boerhaave and Hales on Kant's early natural philosophic work.

Black is famous for his development of the theories of latent and specific heats (see McKie and Heathcote 1935). Black observes that upon state changes, substances exhibit strange thermal behavior. For instance, when water at its boiling point is provided additional heat, this heat does not increase the observable temperature of the water. Rather, at the temperature of state change, additional heat serves only to convert the water into vapor. Furthermore, this heat remains *latent* in the vapor: when vapor condenses, heat can be drawn out of the vapor, even though its sensible temperature is constant.

Additionally, Black finds that different substances have different capacities for heat. For instance, when equal volumes of different substances at the same temperature are placed in equal volumes of water, the substances will change the sensible temperature of the water to different degrees. Hence, each substance has a different capacity for heat (different *specific* heats): each has a characteristic ratio between its sensible temperature and its heat transfer.

Such developments lead many chemists to endorse a material theory of heat, according to which heat is not the mere motion of corpuscles, but rather a substance that can *chemically combine* with other substances. The varying behavior of substances with respect to heat is then due to their variable chemical affinity with heat. Just as different substances combine with each other in different ratios, different substances have different affinities for heat. The idea that heat chemically combines with substances was central to Lavoisier's antiphlogistic theory of chemistry (see below). Karsten discusses the discovery of latent and specific heats, including a table of specific heats in his text (AKN, 29.496f.).<sup>34</sup>

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<sup>34</sup> For more on theories of heat as background for Kant's thought, see Friedman (1992b: 264–90).

### 3.3. Antiphlogistic Chemistry

Lavoisier's system of chemistry involves a variety of developments. At the center of Lavoisier's theory is his reconceptualization of inflammability phenomena. Due to experiments on sulfur and phosphorus conducted in 1772, Lavoisier believes that during combustion, something is not *lost* from a burning substance, but rather something is *gained*. Sulfur and phosphorus gain weight during combustion, and Lavoisier contends that his experiments show that during these processes, the gain in weight is attributable to air being fixed into the combusting substance. So, where the phlogistonist sees phlogiston expelled during combustion, Lavoisier sees gas added. In 1775, Lavoisier presents his "Memoir on Combustion" to the Royal Academy, now claiming that it is not air that affixes itself to a combusting substance, but rather only a fraction of atmospheric air: to wit, Priestley's dephlogisticated or pure air (Lavoisier 1952: 171).

To be clear, Lavoisier thinks of pure air as a compound consisting of a base of pure air and caloric (or heat), and only the *base* combines with a combusting substance. Lavoisier conceives of the caloric as a subtle, elastic fluid that can chemically combine with substances (1952: 170, 172). When enough caloric is added to a substance, it may communicate its subtlety and elasticity thereto, effecting a state change to gas. Upon combustion, the base of the pure air combines with the combusting substance, and the caloric conversely is released (causing the associated flames and sensible heat). The combination of the base of pure air and a metal is a calx, while the combination of the base and a nonmetal is an *acid* (e.g., by combusting and hydrating sulfur or phosphorus, one produces, respectively, sulfuric and phosphoric acid). For this reason, Lavoisier renames pure air 'oxygen'—producer of acidity.



One of Lavoisier's other main contributions is his reconceptualization of elementhood. Lavoisier defends an operationalist account of the elements, according to which elements are those substances that cannot be further analyzed by known processes (and not bearers of properties postulated in advance of inquiry). Lavoisier rejects the elements of his predecessors, for him: air is actually composite, made up of several gases; water is a combination of oxygen and hydrogen; and phlogiston is a fictitious substance, playing no role in combustion. His list is far more extensive, including oxygen, hydrogen, nitrogen, carbon, caloric, light, the metals, and so on (Lavoisier 1965: 175f.).

Lavoisier also places a great deal of emphasis on quantitative measurements in chemistry. Though the consensus amongst historians is that chemists had long appreciated the utility of measurements of weight, Lavoisier especially champions the use of measurements of specific weight.

It is primarily the art of combination that can be illuminated by knowledge of the specific weight of fluids. This part of chemistry is much less advanced than is thought; we hardly know the first elements. Every day we combine acids and alkalis, but how do these two substances unite? do the constituent molecules of the acid enter the pores of the alkali, as Lemery thought, or do the acid and alkali have different facets that somehow engage one another or simply unite on contact, like the hemispheres of Magdebourg? How are acids and alkalis held separately in water? How are they held after they combine? Does the salt that is formed simply occupy the pores in water? Is there simply a division into particles, or is there a real combination, whether between individual particles or between one particle and many others? Finally, where does the air that escapes with such liveliness at the moment of reaction come from, air which, when in its natural state of elasticity, all at once occupies a volume enormously greater than that of the two fluids from which it emerges? Does this air exist from the outset in the two compounds? Was it in some way fixed, as Mr Hales and most physicists since have supposed, or is it so to speak a factitious air that is, as Mr Eller thought, a product of the combination? Chemistry, when asked to address these possibilities, answers with empty terms, such as similarities, analogies, and frictions [...] which clarify nothing and encourage the mind to be satisfied with words alone. If it is

possible for the human mind to penetrate these mysteries, it can hope to do so through research on the specific weights of fluids. (OL, III.449f.)<sup>35</sup>

Lavoisier generally recommended that chemistry appropriate the methods of experimental physics to push the science forward (Donovan 1993: 51). The aforementioned researches on sulfur and phosphorus from 1772 are viewed by Lavoisier as a great vindication of his methods. With the use of measurements of specific weight, Lavoisier is able to determine the source of the weight gain upon combusting sulfur and phosphorus, thereby solving an open question in chemistry of his day (Donovan 1993: 100–2).

Hermstädt's *System der Antiphlogistischen Chemie*, the first German translation of Lavoisier's *Elements of Chemistry*, and Girtanner's *Anfangsgründe der Antiphlogistischen Chemie*, both published in 1792, are major contributors to the dissemination of the Lavoisierian chemical revolution in the German-speaking world. In Girtanner's text, he presents a variety of arguments against the phlogistic approach to chemistry and discusses many of the key aspects of Lavoisier's theory, including its conception of elements (1792: 1, 16f.), understanding of combustion, conception of the caloric (1792: 19–54), the use of the ice calorimeter (1792: 54–58), and the composition of common air (1792: 58–64).

For Girtanner, chemistry is the science that analyzes bodies and studies their constituent parts (1792: 1). The most fundamental components of analysis are the elements—those simple bodies that likely admit of no further decomposition (Girtanner 1792: 16). Constituent parts of bodies are held together by means of attractive forces or affinities, of which there are three sorts: the affinity of cohesion, by means of which homogeneous parts are held together (Girtanner 1792: 2), the affinity of combination, by means of which heterogeneous parts are held together

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<sup>35</sup> Trans. Donovan (1993: 83).

(Girtanner 1792: 8), and the affinity of decomposition, by means of which heterogeneous substances are combined and another substance is separated (or precipitated) (Girtanner 1792: 11). On the affinity of combination “depends all chemical operations,” for chemical dissolutions all occur through combining the parts of different substances (Girtanner 1792: 8). For instance, salt dissolves in water for the affinity between the salt and water is stronger than the cohesive force of the salt.<sup>36</sup> The combination of a substance in fire involves a special sort of affinity of combination (Girtanner 1792: 9f.). When one melts a substance, one is combining its parts with caloric. When one distills a substance, some of its parts combine with caloric, becoming gaseous, leaving the other parts behind which have a “lesser affinity for caloric” (Girtanner 1792: 10). So Girtanner follows other 18<sup>th</sup> century chemists, like Lavoisier, in claiming that the caloric chemically combines with other substances.

Girtanner describes the antiphlogistic conception of combustion and Lavoisier’s experiments on oxygen in chapter 5 of his book.<sup>37</sup> He, too, distinguishes between oxygen and oxygen gas, thinking of the latter as a combination of the former with caloric. Oxygen, Girtanner insists, is an actual substance given in nature—one that can be measured and weighed—and is not assumed merely hypothetically, like phlogiston (1792: 63). Girtanner then describes Lavoisier’s phosphorus experiments, explaining that upon burning phosphorus, oxygen in ambient oxygen gas combines with the phosphorus, freeing a great deal of caloric. This

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<sup>36</sup> Girtanner’s approach thus resembles, in a sense, the approach of a Newtonian like Geoffroy. Indeed, Girtanner mentions affinity tables in this context, but claims that they suffer from defects (Girtanner 1792: 12–6). First, affinity tables fail to take account of the effect of heat on affinities—substances exhibit different combinational behavior at different temperatures. Second, they assume water to be merely passive in chemical operations. Third, they fail to take account of different levels of saturation. For instance, older affinity theorists overlook the fact that there are both sulfuric and sulfurous acids.

<sup>37</sup> The name for oxygen in German, *Säurestoff*—which is used by Hermbstädt and Girtanner—literally means “acidic material.” Indeed, these early antiphlogistic Germans find good analogues in German for many of Lavoisier’s elemental names (e.g., nitrogen becomes *Salpeterstoff*, hydrogen becomes *Wasserstoff*, caloric becomes *Wärmestoff* and carbon becomes *Kohlenstoff*).

phosphorus-oxygen combination is phosphoric acid: Girtanner hence defends the Lavoisierian thesis that acidification is synthesis with oxygen.

In the afterword of his book, Girtanner includes a confutation of phlogistic chemistry after a section that includes a variety of chemical measurements.<sup>38</sup> He opens his attack by calling phlogiston “hypothetical” and “invented” by Stahl (Girtanner 1792: 462). In the succeeding passages, Girtanner marvels at all the phenomena chemists have explained by appeal to phlogiston, ultimately contending that the extreme fecundity of phlogiston is a mark against the theory (1792: 462–5). He notes that metals gain weight during calcination, a fact that cannot be squared with the phlogistic understanding of calcination (Girtanner 1792: 467). Furthermore, he points out the lack of agreement amongst the phlogistonists regarding the elements’ nature: some believe it is ponderable, others not, while some believe it is identical to inflammable air, others not (Girtanner 1792: 466). In contrast to the methods and theories of the phlogistonists are those of the followers of Lavoisier.

In Mr. Lavoisier’s theory, hypotheses are not assumed, rather all sentences are proven, with the balance and with the scale in hand. Why then would we want to take our refuge with a hypothetical principle, whose existence cannot be proven; which one now declares as heavy, now as light and not heavy, now as negatively heavy; which now goes through the container, and now also does not go through; with a word, out of which one makes anything that one wants? (Girtanner 1792: 467)

In later volumes of his *Physikalisches Wörterbuch*, Gehler also discusses the isolation of dephlogisticated air and its role in Lavoisier’s system (1787–95: 5.432ff.), and he discusses the phlogistic and antiphlogistic understandings of calcination in his entry for metals (1787–95: 5.634ff.).

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<sup>38</sup> For instance, he includes the proportions by weight of simple gasses in compound gases and measurements of specific weight (Girtanner 1792: 455–61).

## CHAPTER 1

### Kant on Chemistry and the Application of Mathematics in Natural Science

As I explained in the introduction, Kant describes three standards for scientific propriety that he holds to be equivalent: to wit, a proper science has *a priori* laws, its cognitions are apodictically certain, and it allows for the application of mathematics.<sup>39</sup> In regard to the latter condition, Kant asserts that “in any special doctrine of nature there can only be as much proper science as there is mathematics therein” (MAN, 4.470)—a requirement I call the ‘mathematization condition.’ Since chemistry fails to satisfy the mathematization condition, it is an improper science. That much is clear, although the manner that mathematics is *supposed* to appear in a natural science is anything but.

There are two central questions regarding Kant’s views on the application of mathematics in chemistry. First, what constitutes the application of mathematics to a proper natural science for Kant? Kant himself was concerned with this topic, asking in his physics lectures “If mathematics is necessary for knowledge of nature, then the question is: how much mathematics is necessary, or how much mathematics ought one bring in?” (DP, 29.99). I argue that answers to these questions present in the literature fall short in two ways. Those of the first sort overlook the role of mathematical construction,<sup>40</sup> while those of the second sort take seriously the role of mathematical construction, but either fail to detail the relations amongst metaphysics, mathematics, and natural science or make the application of mathematics condition too strong to

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<sup>39</sup> In an obscure passage, considered in detail in chapter 3, Kant argues for the equivalence of these conditions (MAN, 4.470).

<sup>40</sup> Körner (1955), Brittan (1978, 1986), and Duncan (1986) belong to this class.

satisfy.<sup>41</sup> Second, in what sense does chemistry fail to adequately allow for the application of mathematics? No adequate answer to this question is available in the literature. Few commentators give more than a cursory account of chemistry's status in MAN; those that delve deeper, I argue, unfortunately apply incorrect standards of mathematical application.<sup>42</sup>

In this chapter, I explain why Kant believes that chemistry is an improper science in MAN. In section 1, I describe how mathematics is supposed to appear in a proper natural science. I contend that the concepts of a proper natural science must be coordinated with constructible, mathematical concepts to adequately allow for the application of mathematics. In section 2, I explain how mathematical coordinations are justified in the proper science of physics. I argue that Kant's phoronomy (kinematics) *a priori* coordinates motions with mathematical constructions and that other physical attributes can be mathematically treated only to the extent that they are reducible to the coordinated doctrine of motion. Finally, in section 3, I claim that chemistry is an improper science because it has no *a priori* principles of coordination and cannot be reduced to the doctrine of motion.

## 1. How to Apply Mathematics in Proper Science

In MAN, Kant demonstrates the possibility of *a priori* cognition in special natural science. Special natural sciences (or special doctrines of nature), for Kant, are systematic bodies of cognitions of objects *determined by some empirical concept*.<sup>43</sup> For example, physics is the science of the empirical concept of matter. It is possible to attain *a priori* knowledge of objects

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<sup>41</sup> Friedman (1992b, 2013), van den Berg (2011), and Westphal (1995) belong to this class.

<sup>42</sup> Especially Nayak and Sotnak (1995) and van den Berg (2011): see below for more on these interpretations.

<sup>43</sup> For sake of brevity, I use the term 'science' to refer to special natural science, although, as I mentioned above, Kant believes that there are some general and non-natural sciences.

as such in the *general* doctrine of nature (or general metaphysics). However, Kant believes that *mathematics* makes possible *a priori* knowledge of objects determined by some empirical concept: “although a pure philosophy of nature in general, that is, that which investigates only what constitutes the concept of a nature in general, may indeed be possible even without mathematics, a pure doctrine of nature concerning *determinate* natural things (doctrine of body or doctrine of soul) is only possible by means of mathematics” (MAN, 4.470).

A natural reading of the mathematization condition holds that what makes possible the application of mathematics to a science is the quantitative measurability of that science’s subject matter. Körner (1955: 81) defends this interpretation and argues that the principle of the Anticipations of Perception—“**In all appearances the real, which is an object of sensation, has an intensive magnitude**, i.e., a degree” (KrV, B207)—makes possible the properly scientific treatment of psychometrics and econometrics. Körner contends that, since all perceptions are magnitudes, we can assign quantitative measures to perceptions and then develop mathematical laws that apply to them. Whereas psychology is improper, according to Körner, because it is concerned with a non-quantitative phenomenon (the spirit), psychometrics is a proper science because the natural phenomena with which it is concerned (the intensities of sensations) are measurable. This interpretation is also defended by Dussort (1956), who contends that Lavoisier’s antiphlogistic chemistry was considered proper, by Kant, in virtue of its utilization of quantitative measurements, particularly those by means of the balance (see chapter 3). Brittan (1986: 65, 1978: 103) offers a similarly weak interpretation when he claims that a

concept is mathematically constructible when there is a metric for it, i.e., when there is an addition rule for instances of the concept.<sup>44</sup>

However, there is evidence against this interpretation. In particular, it leaves chemistry's impropriety unexplained. As I explained in the prologue, texts to which Kant was exposed, including AKN and Erxleben (1772) discuss chemical, quantitative measurements in detail, especially those connected with pneumatic chemistry: e.g., measurements of airs' pressures and specific gravities. Furthermore, Karsten discusses a variety of measurement devices including the thermometer (and relevant temperature scales), the aerometer, the barometer, the pyrometer, and the eudiometer (AKN, 29.199–203, 344ff.). Wallerius also goes over the balance, the thermometer, the barometer, and the hydrometer (1761: 58, 67). In addition, as I noted in the prologue, Kant knew of Hales' statical method of chemistry, which emphasized quantitative measurements, by the 1750s. Since Kant knew that quantitative measurement was a part of chemical practice in his day and nevertheless believed the science to inadequately allow for the application of mathematics, quantitative measurement cannot be the standard of mathematical application. Furthermore, as I noted above, Kant presents three criteria for the propriety of a science that he holds to be equivalent. Namely, a science is proper if and only if its laws are *a priori*, its cognitions are apodictically certain, and it makes possible the application of mathematics. If the application of mathematics amounts to quantitative measurability of the

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<sup>44</sup> Nayak and Sotnak (1995) claim Kathleen Okruhlik (1986) defends an interpretation that falls in this class. Okruhlik claims that the regulative ideas of chemistry (pure water, pure air, pure earth, etc.) do not allow for the application of mathematics because they are outside the bounds of possible experience (1986: 311f.). She does not, however, make the further claim quantitative measurability of a science's subject matter makes that science proper. The attribution of this view to Okruhlik appears to be in error. Nayak and Sotnak also cite Abraham Wolf as another who adopts the measurement conception of the applicability of mathematics. Indeed, Wolf writes that

[Kant] did not regard psychology as a science, or as ever likely to become a science. For he identified science with the exact, quantitative treatment of phenomena, so that every science must be mathematical, according to him; and he did not think that mental processes could ever be measured, so that psychology could never become mathematical. (Wolf, 1939, 692)



science's subject matter, the equivalence amongst these conditions breaks down. Measurability clearly does not imply the *a priori* of the science's laws or the certainty of its cognitions.<sup>45</sup>

This proposal fails because it makes the mathematization condition too weak. Indeed, Kant is clear that the application of mathematics must involve the *mathematical construction*: “in order to make possible the application of mathematics to the doctrine of body, which only through this can become natural science, principles for the *construction* of the concepts that belong to the possibility of matter in general must be introduced first” (MAN, 4.472).<sup>46</sup> To make sense of Kant's conception of proper science, I thus first explain mathematical construction.

Kant's doctrine of mathematical construction is described in *The Discipline of Pure Reason in Dogmatic Use of KrV* (A712–738/B740–766). There Kant explains that mathematical cognitions depend upon construction of concepts, where “to **construct** a concept means to exhibit *a priori* the intuition corresponding to it” (KrV, A713/B741). Mathematical demonstrations are mediated by particular instances of mathematical concepts, either imagined or drawn. Nevertheless, knowledge derived in this way can be *a priori*, for one can abstract from the particular empirical peculiarities of any individual imagined or drawn figure.<sup>47</sup>

The individual drawn figure is empirical, and nevertheless serves to express the concept without damage to its universality, for in the case of this empirical intuition we have taken account only of the action of constructing the concept, to which many determinations, e.g., those of the magnitude of the sides and angles

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<sup>45</sup> Van den Berg (2011: 19) makes a similar argument.

<sup>46</sup> See also, for instance, (MAN, 4.470–3, 486f., 493–5). I take Kant's repeated assertion that mathematical construction is essential to proper natural science literally, in opposition to, for instance, Körner, Brittan, and Duncan, who weaken Kant's notion of mathematical application. In MAN (4.470), Kant presents an argument for the thesis that for a special science to have *a priori* laws—an essential mark of propriety—its concepts must be constructible. This argument is considered in detail in chapter 3.

<sup>47</sup> Kant's emphasis on singular figures reveals the significance of then-contemporary geometrical practice on his conceptualization of mathematics. Shabel (2003) provides an exemplary description of this context and its influence on Kant's philosophy of mathematics.

are entirely indifferent, and thus we have abstracted from those differences, which do not alter the concept of the triangle. (KrV, A714/B742)

For Kant, mathematical concepts are grasped along with their construction procedures; e.g., to know the concept of triangle is to know how to produce particular triangles. Possessing a concept's construction procedure then allows one to distinguish those features of the individual figure that are idiosyncratic to the mode of presentation from those that hold universally of all objects falling under the concept, that is, those that hold of an object in virtue of its being produced by that very construction procedure.

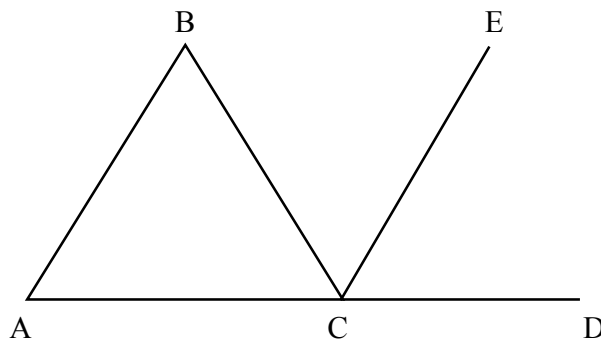


Figure 2: Euclid's I.32

Consider, for example, Euclid's Proposition 32 from Book I of the *Elements*, discussed by Kant in the Discipline (KrV, A716f./B744f.). Proposition 32 is the theorem that the interior angles of a triangle sum to two right angles. According to Kant, the mathematician proves this theorem by producing a particular triangle. That is, she begins with three line segments, any two of which are longer than the third, and constructs a particular triangle  $ABC$  (Figure 2). Afterwards, she completes the requisite additional constructions: extending  $AC$  to  $D$  and drawing  $CE$  parallel to  $AB$ . Then, using the angle equality theorems, she infers that  $\angle BAC = \angle ECD$  and that  $\angle ABC = \angle BCE$ . Finally, as  $\angle ACB$ ,  $\angle BCE$ , and  $\angle ECD$  sum to two right angles, so too do  $\angle ACB$ ,  $\angle ABC$ , and  $\angle BAC$ . At this point, the mathematician has shown that the interior angles of

the individual triangle  $ABC$  sum to two right angles. Her possession of the construction procedure for triangles allows her to infer that this feature holds universally of triangles. She recognizes that no matter the lengths of the three line segments that make up the triangle (as long as any two of them are longer than the third) and no matter their configuration in the triangle, the succeeding constructions (extending  $AC$  to  $D$  and drawing  $CE$  parallel to  $AB$ ) will show the triangle's interior angles to sum to two right angles. Thus, the construction procedure allows the mathematician to secure the universality (and hence *a priori*) of the theorem.

Kant analogously believes that constructed intuitions support inferences in proper natural science. For Kant, physics is the science of matter, conceived of as that which is movable in space (MAN, 4.480). So spontaneously produced intuitions must exhibit the content of the concepts of the science of matter, concepts such as motion, its composition, and its communication. Indeed, throughout MAN, Kant presents principles of mathematical construction for the concepts of physics. For instance, in the Phoronomy, Kant explains how to mathematically represent a motion. One must first recognize that motions have a magnitude and direction (MAN, 4.480, 487). This recognition justifies representing motions with line segments, which then allows for the derivation of further principles regarding motion.

Further *a priori* facts of motion can be derived via the production of particular intuitions exhibiting the concepts of matter and motion. For instance, in the single phoronomic proposition, Kant explains how to compose motions (represented as line segments), deriving the parallelogram law (MAN, 4.490–3). If one is given two distinct line segments,  $AB$  and  $CD$ , that each represents a motion, one represents the combined motion as follows (Figure 3). One motion, say  $AB$ , is conceived of as occurring in a particular background space held to be stationary. Then one conceives of another space that is at motion with respect to the first. This

second space's motion is opposite to  $CD$ , such that a point that is stationary with respect to the first space will have motion  $CD$  with respect to the second. Then the motion  $AB$  with respect to the second space represents the composed motion ( $EF$ ). Thus construction procedures allow for the *a priori* derivation of mathematical laws for natural science.

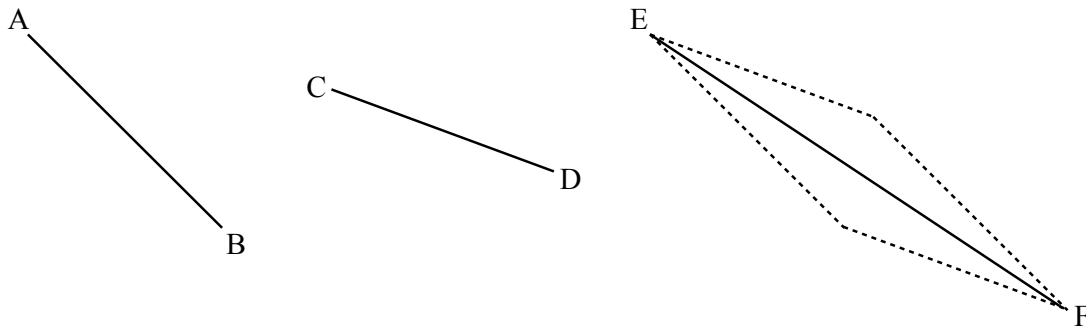


Figure 3: The Composition of Motions

There is a critical qualification to Kant's claim that the concepts of a proper natural science must be constructed. Given Kant's account of mathematical construction from the Discipline of KrV, the concepts characteristic of a special natural science cannot *literally* be constructible (in the strict sense).<sup>48</sup> As I noted previously, what distinguishes a special natural science from general metaphysics is that the former seeks *a priori* cognitions regarding a particular *empirical* concept; so, for instance, physics concerns the empirical concept of matter.

However, empirical concepts are not amenable to mathematical treatment. There are two conditions for mathematical construction that are not satisfied by empirical concepts.<sup>49</sup> First, possession of a mathematical concept is sufficient for the representation of an object falling under it (KrV, A729f./B757f.). That is, the mere possession of the concept of triangle allows the mathematician to spontaneously produce a triangle for utilization in a proof. Possession of an

<sup>48</sup> The only commentator that addresses this problem is Plaass (1965): see below.

<sup>49</sup> See Heis (n.d.).

empirical concept, on the other hand, does not make possible the representation of an object falling under it. For instance, grasping the concept of tree (knowing that a tree is a woody, branching plant) is insufficient for the production of a tree. One can only come across given trees in experience. Consequently, one cannot take the first step towards constructing an empirical concept: to wit, the spontaneous production of an intuition corresponding to the concept.

But even if one could spontaneously produce such instances, one could not use these instances to support inferences to *a priori* knowledge. Mathematical concepts are *made*, while empirical concepts are *given*, which means that to clarify the content of an empirically given concept, one can provide *expositions*, but never *definitions* (KrV, A727–30/B755–8).<sup>50</sup> That is, for an empirically given concept, one can only catalogue the marks of the concept that one has come upon; one can never be certain that one possesses a *complete* list of marks.<sup>51</sup> Such a complete, exhaustive list of marks of a concept would be a concept's *definition*.

Mathematical concepts, on the other hand, are *made*: each contains an arbitrary synthesis of marks and is grasped *along with its definition*. In mathematics, “I can always define my concept: for I must know what I wanted to think, since I deliberately made it up, and it was not given to me either through the nature of the understanding or through experience” (KrV, A729/B757). So to grasp a mathematical concept is to grasp *all* its marks.<sup>52</sup> This feature is crucial to the success of mathematical construction. In the course of a demonstration, the mathematician must be able to distinguish between those features of the construction that belong

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<sup>50</sup> This claim also appears in Log (9.141–3).

<sup>51</sup> For Kant, the marks of a concept, C, are those other concepts that constitute the meaning of C. The marks of C are those concepts contained *in* C (Log, 9.58, 95). For example, the concepts of rationality and animality are marks of the concept humanity.

<sup>52</sup> To put this a bit more carefully, to grasp a mathematical concept is to grasp all of its *immediate* marks. Mediate marks of a concept are those that are marks of marks of the concept: see (V-Lo/Blomberg, 24.108).

to the relevant mathematical concepts and those that are mere idiosyncrasies of the particular constructed token (e.g., that triangle *ABC* is equilateral, that it is printed in black ink). If the mathematician cannot differentiate these sorts of qualities, she may misidentify those properties that hold universally of the relevant mathematical concepts. But in order to categorize the features of the diagram in this manner, she requires an exhaustive *definition* of the relevant mathematical concepts. For this reason, one cannot use mathematical construction to gain *a priori* knowledge of empirical concepts. Since an empirical concept is given and indefinable, one cannot distinguish with certainty those features of a particular token that belong to the concept from those that are unique to that token.

Consequently, the application of mathematics to a proper natural science cannot be thought of as demanding the construction of the *empirical*, natural concepts, themselves. Mathematical concepts are the only constructible concepts. I contend that, for Kant, mathematization condition rather requires the *coordination*<sup>53</sup> of that science's concepts with mathematical constructions.<sup>54</sup> That is, in lieu of actual construction procedures for empirical, natural concepts, one can pair them with surrogate mathematical concepts. Our construction of these mathematical concepts will then yield conclusions that can be translated (via the

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<sup>53</sup> This suggestion is inspired by Reichenbach. Note that metaphysics is the arbiter of coordination principles for Kant, whereas experience plays this role for Reichenbach (1965: 34–47).

<sup>54</sup> This qualification on the construction of scientific concepts is new to the literature. Plaass (1965) is the only commentator who is similarly troubled by the application of mathematics to the empirical concepts of physics. Plaass argues that the content of the concept of matter is entirely *a priori* and that the concept is empirical only in the sense that experience is required to secure its real possibility (Plaass 1965: 86–8). I disagree for two reasons. First, the concept of matter has empirical content. Kant explicitly claims this in the preface to MAN (4.472). Indeed, throughout MAN, the concept of matter is *explicated*: a type of analysis characteristic of *empirical* concepts. Second, there is little support for Plaass' account of the *a priori* of the concept of matter. Plaass claims that the *a priori* content of the concept of matter is specified through a procedure he calls "metaphysical construction" (1965: 74–9). However, Plaass provides scant evidence for the place and role of metaphysical construction in MAN, citing a single ambiguous sentence (MAN, 4.473). As Friedman notes, Plaass' metaphysical construction is problematic, given that Kant argues that construction is what *distinguishes* mathematics from metaphysics in the Discipline (Kant 2004: 9n.).

coordinations) into judgments of natural science. In the next section, I explain how Kant thinks metaphysics justifies these coordinations. That said, that application depends upon coordination avoids the obstacles to constructing empirical concepts. For instance, in the aforementioned phoronomic case, that motions are coordinated with line segments allows one to *spontaneously produce* intuitions that support inferences to pieces of general, physical knowledge. Moreover, since the concept of a line segment is mathematical, it is *exhaustively definable*, meaning that one can distinguish between those features of a phoronomic construction that are had merely by the mode of presentation.

## 2. Why Physics is a Proper Science

If coordinations are *necessary*, as they *must* be in the pure part of a proper science, then they require *a priori* grounding. In this section, I explain how Kant grounds the coordination of the mathematical and physical in *a priori* metaphysics. This explanation clarifies the stringent conditions on coordination in proper science. I maintain that there are two sorts of coordination principles in physics. Of the first sort is the coordination of composite motions in the phoronomic proposition. This coordination is *a priori*, I argue, in virtue of being necessary for the possibility of experiencing objects of the outer sense. Of the second sort is the coordination of the filling of space in the Kant's dynamics. Since Kant shows that this phenomenon can be reduced to a sort of effect on motion and composite motions are coordinated in his phoronomy, the filling of space too can be coordinated with a mathematical construction. Hence, the coordinated doctrine of motion lays the groundwork for Kant's mathematical physics.

In order to understand the nature of this groundwork for mathematical physics, I first need to explain (another aspect of) Kant's project in MAN. As Watkins (1998: 577f.) argues, an

objective of MAN is to account for the possibility of experiencing objects of outer sense. To achieve this goal, Kant first claims that “[t]he basic determination of something that is to be an object of the outer senses had to be motion, because only thereby can these senses be affected” (MAN, 4.476). Physics, originally defined as the science of the objects of outer sense, is therefore equally the science of matter (the movable in space). To explain the possibility of experience of outer objects, Kant then adopts a similar argumentative strategy to that deployed in KrV. In KrV Kant shows that an object of possible experience must be determinable according to the categories; MAN demonstrates the way in which the concept of matter is so determinable, thus making objects of outer sense possible objects of experience.<sup>55</sup> So in MAN describes the sense in which the concept of the movable in space is determinable by the categories. That is, in each chapter of MAN, Kant introduces a new determination of matter and argues that it corresponds with a categorial determination. This process secures the possibility of experiencing matter (and hence objects of outer sense) and also exhaustively produces all that may be *a priori* known about matter (MAN, 4.474–6).

For instance, the Phoronomy corresponds to the category of *quantity*; so it is supposed to present a determination of the concept of matter that is a magnitude. Kant argues that motion is the quantity of physics.

In phoronomy, since I am acquainted with matter through no other property but its movability, and may thus consider it only as a point, motion can only be considered as the describing of a space—in such a way, however, that I attend not solely, as in geometry, to the space described, but also to the time in which, and thus to the speed with which, a point describes the space. (MAN, 4.489)<sup>56</sup>

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<sup>55</sup> This is the sense in which the special metaphysics of MAN provides “instances *in concreto*” of the content of general metaphysics (MAN, 4.478).

<sup>56</sup> See also (KrV, B155n.).



Kant's claim in this passage is that motions can be coordinated with spaces: the motion of a point (which is what is at issue in phoronomy) is coordinated with a line segment. The line segment represents the space traversed (the direction and distance). But in phoronomy one also takes notice of the duration of the displacement. The selfsame segment *AB* represents a different motion if it is traversed in one second versus one minute.

As Friedman (2012: 485f.) notes, to show that motions are magnitudes is just to show how two motions may be combined into another motion.<sup>57</sup> Hence, to demonstrate that motions are magnitudes (and thus to show how the concept of matter is determinable by the category of quantity), Kant *coordinates the concept of a composite motion with a constructive procedure*.

To **construct** the concept of a *composite motion* means to present a motion a priori in intuition, insofar as it arises from two or more given motions united in one movable. (MAN, 4.486).

The parallelogram law, discussed above, shows that the concept of matter is determinable by the category of *quantity* and also coordinates the concept of a composite motion with a particular mathematical construction.

Such principles of coordination—between motions on one hand and mathematical constructions on the other—are *necessary*.<sup>58</sup> For matter to be a possible object of experience, it must be determinable by the categories, including the category of quantity. But for matter to

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<sup>57</sup> Kant employs a traditional notion of magnitude, according to which different types of magnitude each have their own addition relation. According to such an addition relation, two magnitudes of a given type added together yield another magnitude of that same type. So to show that something is a magnitude, one must fix an addition relation for it: see Friedman (2013: 53–5) and Sutherland (2004).

<sup>58</sup> Van den Berg (2011) recognizes the importance of mathematical construction for proper natural science but overlooks the role of metaphysics in validating the application of mathematics. Ultimately, he asserts that mathematical application is only made possible by discovering empirical regularities (van den Berg, 2011: 23f.). Certainly, in the empirical part of a proper science, experience may inform the theory; however, there must be a pure core of the science that can be *a priori* coordinated with mathematical constructions. Kant is clear that the pure parts of a proper science (i.e., what is described in MAN) have nothing of experience intermixed (MAN, 4.469), meaning that laws of a proper science must have *a priori*, metaphysical grounds.

have a quantity, composite motions must be coordinated with mathematical constructions as depicted in the parallelogram law. The phoronomic construction is consequently necessary for the possibility of experiencing matter. *But* in physics the concept of matter stands in for the concept of object of the outer sense. The phoronomic proposition's coordination of the physical and mathematical is therefore necessary for the possibility of experience of objects of the outer sense. It is this sense in which the phoronomic coordination is non-arbitrary, *a priori*, and necessary.<sup>59</sup>

This is the pure core of the doctrine of motion, which then allows for the coordination of other aspects of physics with mathematical constructions.

The concept of matter had therefore to be carried through all four of the indicated functions of the concepts of the understanding (in four chapters), where in each a new determination of this concept was added. The basic determination of something that is to be an object of the outer senses had to be motion, because only thereby can these senses be affected. The understanding traces back all other predicates of matter belonging to its nature to this, and so natural science, therefore, is either a pure or applied *doctrine of motion*. (MAN, 4.476f.)

Thus, in the subsequent chapters of MAN, Kant reduces the *quality*, *relation*, and *modality* of objects of the outer sense to the pure core of the doctrine of motion. The quality and relation of matter are respectively the filling of space and the communication of motion, which are defined entirely in terms of their effects on motion, while the modalities of matter are motions that

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<sup>59</sup> Scholars disagree about the kind of *a priori* that accrues to the propositions of MAN. Buchdahl (1966, 1971) contends that there is a 'looseness of fit' between the principles of the pure understanding and those of physics. The latter may be empirically disproven and replaced, while the former, being constitutive of experience, may not. Brittan (1978: 155) claims that they are *a priori* in the sense that they are true in all worlds where the concept of matter has application. For Kitcher (1983: 393–400), experience legitimates the concept of matter, and the propositions of MAN are *a priori* in the sense that no *further* experience is necessary to justify them. Alternatively, one may claim that the propositions of MAN are necessary for the possibility of experience. As observed above, to account for the real possibility of matter is to account for the possibility of outer experience. But according to the Refutation of Idealism, inner experience, and thus experience, generally, requires experience of outer objects (KrV, B274–9). However, the precise sense of *a priori* of the principles of MAN is not crucial for my account. The most that need be said for our concerns is that the principles of proper science are *a priori* insofar as they are necessary for matter to be an object of experience. For a brief treatment of various views on the *a priori* of the laws of proper natural science—especially in relation to Kitcher—see Parsons (1984).

accord with particular constraints. The central point is that the quality, relation, and modality of matter can be represented in *composite* motions, whose mathematical coordinations are made possible by the phoronomic proposition.

A detailed consideration of mathematical coordination in the Dynamics of MAN is necessary to fill out this interpretation and to prepare the ground for our consideration of chemistry in section 3. In Kant's dynamics, he claims that the quality of matter is the filling of space, that is, the resistance of a matter to other matters penetrating its space. The filling of space is conceived of entirely in terms of its effects on motion.

Penetration into a space (in the initial moment this is called a striving to penetrate) is a motion. Resistance to motion is the cause of its diminution, or even of the change of this motion into rest. Now nothing can be combined with a motion, which diminishes it or destroys it, except another motion of precisely the same movable in the opposite direction (Phoron. Prop.). Therefore, the resistance that a matter offers in the space that it fills to every penetration by other matters is a cause of the motion of the latter in the opposite direction. But the cause of a motion is called a moving force. Thus matter fills its space through a moving force, and not through its mere existence. (MAN, 4.497)

The reduction of the filling of space to an effect on motions opens the door to coordination of the filling of space with a mathematical construction. A body,  $\alpha$ , resisting the penetration of another,  $\beta$ , via  $\alpha$ 's filling of its space can be mathematically represented by the composition of  $\beta$ 's motion with a contrary motion that represents the strength of  $\alpha$ 's resistance. That the composition of motions is constructible via the phoronomic proposition means that such a scenario can too be coordinated with a mathematical construction.

This coordination is *a priori* because it is necessary for matter be determinable by the category of quality (and thus necessary for the possibility of experiencing objects of the outer sense). Qualities, for Kant, are *intensive magnitudes*, that is, continuous magnitudes capable of degrees (KrV, A165/B208). As Daniel Warren (2001b: 22–31) has helpfully shown, intensive

magnitudes are those that result from *causal powers*.<sup>60</sup> That is, the crucial feature of that which falls under the category of quality is that it is a property whose quantity is measured not according to its parts, but according to the effects that it produces.<sup>61</sup> “[T]hus,” Warren writes, “a reality (a sensible quality) is represented as a determinate magnitude through its causal relations to effects which are unproblematically quantifiable” (2001b: 26). The phoronomic proposition justifies the claim that the filling of space is a quality by making composite motions “unproblematically quantifiable” (for the effect of the filling of space is a sort of composite motion). Then, in proposition 2 of the Dynamics, Kant shows that the filling of space has a *degree* (MAN, 4.499). The filling of space is thus the quality of physics, and the associated coordination of this quality with a continuously variable quantity is consequently necessary.

Not all concepts of proper natural science can be *a priori* coordinated with mathematical constructions. Take, for example, the fundamental attractive and repulsive forces. In propositions 2 and 5 of the Dynamics, Kant respectively argues that these two forces are essential to matter for it to fill space (MAN, 4.499, 508f.). The repulsive force explains the diminution of motion into the space of that matter, while the attractive force offsets the repulsive force, which guarantees that matter does not disperse infinitely (as it would if only the repulsive force were essential to matter). This introduction of the attractive force does not depend upon the mere empirical fact that matter is not infinitely dispersed; rather, the infinite dispersal of matter would

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<sup>60</sup> For Warren, the notion that qualities have degrees (KrV, A165/B208) is derived from their being effects of causal powers (Warren 2001b: 28).

<sup>61</sup> Warren (2001b: 26) emphasizes Refl 5663, in which Kant explains that heat is a magnitude, whose intensity/degree is determined by evaluating its effects (18.322).

mean that is not the *quality* of physics.<sup>62</sup> Yet, Kant coordinates neither fundamental force with a mathematical construction. Furthermore, he suggests that the coordination of the fundamental forces of attraction and repulsion is *impossible* in the General Remark to the Dynamics (MAN, 4.524f.).

A number of commentators have been perplexed by this apparent lacuna in Kant's dynamics.<sup>63</sup> Our understanding of Kant's project allows us to recognize that Kant need not and cannot *a priori* coordinate the fundamental attractive and repulsive forces with mathematical constructions in MAN but nevertheless that MAN lays the groundwork for the possibility of their coordination.<sup>64</sup> As I observed above, in order for matter to be determinable by the categorial heading of quality, the filling of space needs to be reducible to the composition of motions. This implies that the fundamental forces can be coordinated with mathematical constructions, *but does not require any particular coordination*. The transcendental role of the filling of space (with respect to the concept of matter) entails only certain *constraints* on the coordination of these forces. For instance, the laws governing the diffusion of the two forces cannot be equivalent, for then the filling of space could not have *degrees* and thus would fail to be a

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<sup>62</sup> Were matter infinitely dispersed, the filling of space would be incapable of having different degrees in different spaces, meaning that all space would be unfilled. In this case, the filling of space could not be a quality, since it is nowhere exemplified.

<sup>63</sup> Interpreters have reacted in a variety of ways to Kant's apparent denial of the constructibility of the fundamental forces. One group of scholars claim that Kant's project in MAN ought to be amended or reconceptualized; Buchdahl (1986), Butts (1986), and Friedman (1992b: 195n.) defend versions of this thesis. Friedman (2013) contends that, outside the Phoronomy, Kant seeks a kind of mathematization that falls short of the construction of physical concepts. Others think that the context of the Remark reveals that Kant's project of mathematically constructing the concept of matter is no failure; Duncan (1986) and Förster (2000: 65f.) argue for interpretations in this category (as do I). The final group of interpreters claims that Kant's difficulties with the mathematical procedure in MAN reveal incoherence in his Critical philosophy; see Brittan (1986) and Westphal (1995: 388–404).

<sup>64</sup> So, in the Remark, Kant only means to rule out the possibility of constructing forces that do *not* belong to the possibility of matter (in this regard, my understanding of this issue is akin to Förster's). The fundamental forces of attraction and repulsion belong to the possibility of matter, while the forces that explain the specific variety of matter do not (MAN, 4.524).

quality. Nonetheless, Kant presents a possible coordination—that is, one that accords with the transcendental requirements—in the second remark to proposition 8 of the Dynamics (MAN, 4.518–22). But the actual coordination principles for these forces, whatever they may be, are beyond the bounds of metaphysics, for the possibility of matter as an object of experience does not require any *particular* coordinations (MAN, 4.517f).<sup>65</sup>

The grounds for the coordination of the fundamental forces will ultimately be empirical. [...]no law of either attractive or repulsive force may be risked on a priori conjectures. Rather, everything, even universal attraction as the cause of weight, must be inferred, together with its laws, from data of experience. (MAN, 4.534)

Nevertheless, the science of the fundamental attractive and repulsive forces—dynamics—is not consequently an improper science. The *particular* coordination principles for these forces lay in the *empirical part* of the proper science of physics.<sup>66</sup> Physics remains a proper science, for it still has a pure part: the doctrine of motion. This pure part makes possible coordinations for the fundamental forces of attraction and repulsion; there must be such coordinations, whatever their specific, empirically derived content may be, in order for matter to be an object of possible experience. So dynamics belongs to the empirical part of the proper science of physics.<sup>67</sup>

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<sup>65</sup> Thus, as Duncan claims, the problem of constructing the fundamental attractive and repulsive forces is merely the problem of discovering the appropriate mathematical surrogates (1986: 290–4). However, Duncan’s notion of construction differs from my own, as he conceives of construction as primarily validating reasoning about unobservables by making them visualizable (1986: 277–84). This interpretation of construction, however, cannot explain the equivalence of the three standards of propriety.

<sup>66</sup> Kant claims that a proper science has a pure part and an empirical part: the pure part contains its *a priori* principles, while the empirical part has principles that require experience (MAN, 4.469). That proper sciences have pure and empirical parts conflicts with Nayak and Sotnak’s (1995: 148) claim that the empirical component of chemistry makes it an improper science.

<sup>67</sup> A detailed description of Kant’s mechanics is beyond the concerns of this chapter: this brief note must suffice. I claim, following Watkins (1998: 582–7), that the communication of motion is the *relation* of matter, meaning that it is necessary for the possibility of experiencing matter. The coordination of the communication of motion with a mathematical construction, which represents the communication of motion in the reference frame defined by the center of mass of the system (MAN, 4.544–7), requires that the masses of the interacting bodies be determinate quantities. For masses or aggregates of the movable in a space to be quantities, one must have a rule for their composition; such a rule is made possible by the coordination of the quantity of matter with a mathematical

There are thus *a priori* principles that make possible the coordination of the concepts of physics with mathematical constructions. These principles include the pure doctrine of motion and those validating the reduction of the further physical determinations of matter to composite motions. Mathematical coordination in physics, even when it requires empirical evidence, as it does in dynamics, depends for its possibility on the pure, coordinated part of the proper science.

### 3. Why Chemistry is Not a Proper Science

So I have shown that the application of mathematics to a proper science consists in the coordination of mathematically constructible concepts with those of the science in question, coordination made possible by *a priori* principles. I now turn to a consideration of chemistry's status as an improper science, an issue that has not been satisfactorily treated in the existing literature; few commentators have been interested in chemistry's scientific impropriety and those who have directly considered the issue have applied inappropriate conceptions of mathematical application.<sup>68</sup> In this section of the chapter, I argue that there can be no *a priori* principles of coordination in chemistry. The science of chemistry, for Kant, concerns particular forces of matter. These forces, however, do not belong to the possibility of matter, and hence cannot be coordinated *a priori*. Furthermore, chemical forces cannot be reduced to the pure doctrine of motion, meaning that chemistry is not in the empirical part of a proper science. These forces

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construction (MAN, 4.538). Friedman (2013: 290f.) thinks that the quantity of matter is not *literally* constructible because the fundamental dynamic forces are not constructible. Since I claim that the fundamental dynamic forces can be legitimately (empirically) coordinated with mathematical constructions, I hold, *pace* Friedman, that MAN makes possible the coordination of the quantity of matter with mathematical constructions.

<sup>68</sup> Nayak and Sotnak (1995) and van den Berg (2011) are led astray by their conceptions of mathematical application. Friedman claims that chemistry would be a proper science were it reducible to the doctrine of motion (1992c: 93). I concur with this point, although reduction of chemistry to physics is merely a sufficient condition for its propriety.

could only be represented by composite motions if their activity were reduced to the interaction of mechanical corpuscles. But such reduction would be metaphysically incoherent. Thus chemistry is improper, and furthermore its impropriety is directly connected with Kant's rejection of mechanical philosophy.

Before considering in detail why chemistry is not a proper science, it is necessary to understand how Kant conceives of chemistry. Perhaps the clearest definition of chemistry in Kant's corpus is found in the loose leaves of OP. In these leaves, in particular leaf 23, Kant contemplates forces beyond the fundamental forces of attraction and repulsion handled in the Dynamics of MAN. In this context, Kant describes chemistry as "the science of the inner forces of matter" (OP, 21.453). Chemistry, like physics or psychology, is a special natural science founded on an empirical concept. Where physics takes the concept of matter at its basis, chemistry takes the concept of an inner force of matter.

But what are *inner forces of matter*? In DP, Kant separates forces (as well as changes of matter) into three kinds: mechanical, chemical, and organic (DP, 29.116f.). According to Kant

Chemical [changes of matter] whereby the innermost constitution of matter is changed, i.e., it becomes different or dissimilar, e.g., oil of vitriol is very corrosive and dissolving, and a compressed oil is least dissolving—combined together, they give sulphur, which has an entirely different nature. So the matter gets an entirely different kind of efficient and active forces. *The chemical forces consist in composition [Zusammensetzen] and decomposition [Scheiden].* (DP, 29.117) (my italics)

Kant makes a similar claim in the General Remark to the Dynamics, where he distinguishes the chemical and mechanical actions of bodies. Bodies act mechanically on each other when they externally communicate motion; bodies chemically act "*insofar as they mutually change, even at rest, the combination of their parts through their inherent [eigene] forces*" (MAN, 4.530).



Chemical action is further divided into dissolution (*Auflösung*) and decomposition (*Scheiden*).<sup>69</sup> Kant then explains that, in dissolution, two matters combine such that every part of the solution contains the same proportion of solvent and solute. The characteristics of such a combination are then different from the reagents, as the sulphur has different properties from the oils it came from in the above passage. Decomposition, by contrast, reverses the combination of the dissolving forces, yielding two distinct matters.

Thus according to Kant chemistry is the science of dissolving and decomposing forces, and the task of the chemist is to discover laws governing such forces. Yet mathematics is not applied in chemistry.

[E]verything, even universal attraction as the cause of weight, must be inferred, together with its laws, from the data of experience. Still less may such laws be attempted for chemical affinities otherwise than by way of experiments. For it lies altogether beyond the horizon of our reason to comprehend original forces a priori with respect to their possibility; all natural philosophy consists, rather, in the reduction of the given, apparently different forces to a smaller number of forces and powers that explain the actions of the former, although this reduction proceeds only up to fundamental forces, beyond which our reason cannot go. (MAN, 4.534)

The laws of chemistry, according to Kant, may only be discovered through experience. One cannot know *a priori* whether the inner forces of matter are really possible, and thus the project of chemistry is to merely *reduce* the various forces of dissolution and decomposition as much as possible.

Chemistry must proceed non-mathematically because neither of the two ways of applying mathematics to chemistry succeeds. First, coordination principles for the inner forces of matter

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<sup>69</sup> As I noted in the prologue, in Germany chemistry was historically called “*Scheidekunst*.” Kant comments that in earlier times, a chemist was called either a “*Mengmeister*” or a “*Scheide Künstler*” though, according to him, the chemist “is both” (DP, 29.117). As I argued in the prologue, many of the scientists to whom Kant was exposed endorsed a definition of chemistry as the science of the dissolution and decomposition of substances.

could belong to the possibility of matter. Second, the activity of inner forces could be reduced to effects on motions, making chemistry an empirical part of physics. I discuss why each option fails in turn.

That chemical forces can be coordinated with mathematical constructions does not belong to the possibility of matter (as does the coordination of, e.g., motion). That is, the forces of dissolution and decomposition do not play any categorial role for the concept of matter: they play no substantive role in the propositions and explications of Kant's phoronomy, dynamics, mechanics, and phenomenology (the four parts of physics). Furthermore, Kant is clear that these doctrines of physics *exhaust* the *a priori* principles regarding matter; "all that may be either thought a priori in this concept [of matter], or presented in mathematical construction, or given as a determinate object" must be given by the categorial determinations of the concept of matter (MAN, 4.475f.). Given that the only ground for *a priori* coordination consists in the categorial determination of the concept of matter and that chemical forces play no categorial role for the concept of matter, these forces are not *a priori* constructible.

Chemistry could be part of a proper science were the action of its forces reducible to the doctrine of motion, as the fundamental attractive and repulsive forces are reducible. However, according to Kant, there are two possible conceptions of the ultimate explanatory grounds in natural philosophy, neither of which can legitimate the reduction of the inner forces of matter to the doctrine of motion.

The physical mode of explanation comprises two modes under itself:

1. The mechanical as one explains something through already available forces. So Descartes explained the dissolution of crab stones [calcium carbonate] by vinegar [acetic acid] mechanically when he supposes the parts of vinegar to be sharp, which therefore penetrate the crab stones as the heat drives the corpuscles into the crab stone as with a warm blow.
2. Dynamical as one lays especially still not available forces at the foundation. In chemistry one explains nearly everything dynamically. The mechanical and

dynamical modes of explanation taken together make the physico-mechanical [mode of explanation]. (DP, 29.105)<sup>70</sup>

Kant distinguishes the two physical modes of explanation—the mechanical and the dynamical—and notes that chemistry proceeds dynamically.<sup>71</sup> This particular division of modes of explanation is echoed in the General Remark to the Dynamics of MAN. There Kant presents these two mutually exclusive and exhaustive approaches to the science of matter. The mathematical-mechanical mode of explanation takes *absolute impenetrability* to be the fundamental property of matter. The mechanist thinks the world is made of absolutely impenetrable corpuscles separated by absolutely empty interstices. The alternative material mode of explanation, metaphysical-dynamism, rejects the mechanical *explanans* of absolute impenetrability and empty space, and instead takes space to be a plenum, wherein all its parts are *relatively* impenetrable to some degree or another. The relative impenetrability of a space is the result of the relative intensity of the fundamental repulsive force in that space. In sum: mathematical-mechanism takes absolute impenetrability at its basis where metaphysical-dynamism takes moving forces at its basis.<sup>72</sup>

Both modes of explanation seek to explain phenomena beyond impenetrability and resistance to motion. The mechanist explains other material phenomena by appeal to the shape,

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<sup>70</sup> By “crab stones” (*Krebssteine*), I take Kant to be referring to gastroliths found in many crustaceans. These gastroliths are primarily made of calcium carbonate and serve to harden the exoskeleton after molting. Friedman (2013: 245) thinks Kant means to refer to rosary peas (seeds from a tropical plant) when he writes of “crab stones.” Two pieces of evidence support my interpretation. First, just as Kant reports, heat is produced as vinegar dissolves calcium carbonate. Second, elsewhere in DP (29.168), Kant recommends consuming “crab stones” to relieve heartburn. Calcium carbonate is a common and effective treatment for heartburn; rosary peas, on the other hand, are extremely poisonous.

<sup>71</sup> This point is made more forcefully in Refl 63, from the 1780s, in which Kant claims that “[c]hemistry *must* proceed dynamically” (14.481) (my italics).

<sup>72</sup> For more on these modes of explanation in Kant’s scientific context, see the prologue, Buroker (1972), and Warren (2001a).

size, and impact of absolutely impenetrable corpuscles against a background empty space. Descartes' account of magnetism, discussed in the prologue, is a paradigm of mechanical explanation.<sup>73</sup> Kant gives another example of mechanical explanation in the discussion of the modes of explanation quoted in the preceding paragraph, a Cartesian explanation of the dissolution of calcium carbonate by acetic acid. On this account, the parts of matter that make up the acetic acid are sharp and thus can penetrate and separate the parts of the calcium carbonate. A mechanical approach to chemistry, then, would generally explain the dissolution and decomposition of matters in terms of the size, shape, and impact of corpuscles.

In contrast, forces constitute the ultimate explanatory basis for the metaphysical-dynamist: "The general principle of the dynamics of material nature is that everything real in the objects of the outer senses, which is not merely the determination of space (place, extension, and figure), must be viewed as moving force" (MAN, 4.523). The dynamist would, therefore, explain a phenomenon such as magnetism by appeal to attractive and repulsive forces, and she would explain the dissolution of calcium carbonate by vinegar by appeal to forces of dissolution that combine the parts of the reagents.

Note that the mathematical-mechanist's explanations are amenable to mathematical treatment, as they refer exclusively to the shape, size, and impact of parts of matter. All such properties can be coordinated with mathematical constructions. The shape and size of corpuscles can be described mathematically, for these parts of matter are just (impenetrable) parts of *space*: the shape of corpuscles can be constructed just as any shape can be. Similarly the motions and impacts of these parts of space will be constructible via the doctrine of motion and the mechanical coordination of material collision; it therefore appears that the mathematical-

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<sup>73</sup> See Part III of his *Principles of Philosophy*, in particular, aa. 158ff. (Descartes, 1991: 259ff.).

mechanical mode of explanation makes possible the application of mathematics to material phenomena in general and the science of dissolution and decomposition in particular. A mechanistic chemistry would thus be reducible to the coordination principles of MAN and be a part of the proper science of physics.

But the mathematical-mechanical mode of explanation cannot achieve mathematical adequacy on account of its metaphysical deficiency. The concepts that constitute the mechanists' explanatory basis—absolute impenetrability and empty space—are empty. Kant deems absolute impenetrability to be “in fact nothing more nor less than an occult quality” (MAN, 4.502).<sup>74</sup> Kant also claims that empty space is not a possible object of perception, a claim made in KrV in both the Anticipations of Perception (KrV, A172–3/B213–4) and the Third Analogy (KrV, A214/B261). The concepts of absolute impenetrability and empty space have a metaphysical status analogous to Newton's absolute space: all are “nonentities” (*Undinge*) (KrV, A39/B56).<sup>75</sup> Furthermore, Kant takes mechanism to entail a rejection of “all forces *inherent* in matter” (MAN, 4.525), which means that mechanism must give up gravity as a universal force of matter, an unacceptable implication.<sup>76</sup>

Like the mechanical approach to chemistry, the metaphysical-dynamical approach fails to make possible the construction of chemical forces, although, where mechanism is metaphysically deficient, dynamism suffers from a distinct defect.

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<sup>74</sup> Kant also claims that absolute impenetrability and empty space comprise “an obstacle to the governance of reason” (MAN, 4.532) and castigates the mechanists for attempting to avoid metaphysical grounding for their mode of explanation (KrV, A173/B215).

<sup>75</sup> Daniel Warren (2001b) argues that the mechanists' project amounts to an attempt to characterize things-in-themselves. See also Langton (1998: 172–7).

<sup>76</sup> See also Refl 63. That dynamism removes an obstacle to realism with respect to Newtonian gravitation is important to Brittan (1986). I concur that this is a noteworthy motivation behind Kant's preference for dynamism, but, as I have argued, the metaphysical incoherency of mechanism also motivates Kant.

And here the mathematical-mechanical mode of explanation has an advantage over the metaphysical-dynamical [mode], which cannot be wrested from it, namely, that of generating from a thoroughly homogeneous material a great specific variety of matters, which vary both in density and (if foreign forces are added) mode of action, through the varying shape of the parts and the empty interstices interspersed among them. For the possibility of both the shapes and the empty interstices can be verified with mathematical evidence. By contrast, if the material itself is transformed into fundamental forces (whose laws we cannot determine a priori, and are even less capable of enumerating reliably a manifold of such forces sufficient for explaining the specific variety of matter), we lack all means for *constructing* this concept of matter, and presenting what we thought universally as possible in intuition. (MAN, 4.524–5)<sup>77</sup>

The metaphysical-dynamical explanations of chemistry, though coherent, cannot be reduced to the pure doctrine of motion. To reduce the inner forces of matter to mathematical physics would require that chemical action be represented by the communication of motion between spaces. Now, for Kant, chemical dissolutions are *absolute*; that is, every part of a chemical solution is homogeneous (MAN, 4.530). So, in a complete chemical dissolution, every single part of the solvent needs to combine with a proportional part of the solute in a *shared* space. But this is to require that during dissolution the reagents' extensions be *absolutely* reduced. That is, chemical dissolution requires material *penetration*. Yet, as Kant shows in proposition 3 of his Dynamics, the communication of motion that may be mathematically represented in physics can only effect a finite compression of matter, never an absolute penetration (MAN, 4.501). So the mathematical coordinations belonging to physics are inadequate for the mathematical representation of chemical forces. Kant also puts this point in another way (see MAN, 5.531). As I noted, the mathematical representation of chemical forces would require the representation of a constant proportion of solvent and solute in every space of the solution. But since matter is infinitely

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<sup>77</sup> Kant makes clear earlier in this passage that this difficulty arises only for forces that do not belong to the possibility of matter (e.g., chemical forces, cohesion, and magnetism). Hence, our earlier account of the propriety of the science of the fundamental attractive and repulsive forces still holds.

divisible (MAN, 4.503), to unify every part of the solution in this way would require a completed division to infinity. But one cannot mathematically represent such a completed infinite division. It is imperative to note that this argument does *not* imply the unintelligibility of chemical forces, as such. Only on the assumption that chemical forces can be represented in the doctrine of motion must one think of their action as requiring a completed division to infinity. Apart from this assumption, one can still speak legitimately of chemical forces, as I explain below and, especially, in chapter 2.

To summarize, chemistry is an improper science according to Kant, because the concepts of chemical forces cannot be constructed. Chemical forces do not belong to the possibility of experiencing matter, so there cannot be *a priori* principles coordinating them with mathematical constructions, and chemical forces cannot be reduced to the doctrine of motion. The mathematical-mechanical approach would reduce chemical forces, allowing for their mathematical representation, were mechanical philosophy not metaphysically inadequate. The metaphysical-dynamical description of chemistry, though metaphysically legitimate, utilizes forces that outstrip the expressive power of the mathematical doctrines of physics. Therefore chemistry is neither a proper science nor a part of the proper science of physics.

Kant nevertheless believes that there is a crucial difference between mechanical and dynamical chemistry. The concepts of dynamical chemistry—decomposition and dissolution—are not incoherent. And so although these forces cannot be mathematically represented, there is nevertheless a legitimate science of these forces.<sup>78</sup> One can observe and experiment with substances in order to systematize and unify knowledge of chemical forces even in the absence

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<sup>78</sup> In what follows, I provide a cursory overview of chemical methodology, in order to make the point that dynamism, in virtue of its metaphysical legitimacy, makes possible explanation whereas mechanism is defunct. My detailed account of chemical methodology appears in chapter 2.

of mathematical foundations, as Kant explained in the above-quoted passage from the General Remark to the Dynamics (MAN, 4.534). Consider the following example, well-known in Kant's time. Metallic silver dissolves in *aqua fortis*; when copper is added to this solution, silver is precipitated out.<sup>79</sup> According to Kant's framework of chemical forces, this observation is explained by the judgment that the dissolving force that acts to combine silver and *aqua fortis* is weaker than the dissolving force between copper and *aqua fortis*.<sup>80</sup> This is a judgment of dynamic chemistry, one that is legitimate despite our inability to coordinate chemical forces *a priori* with mathematical constructions. Thus, the metaphysical-dynamical methodology of postulating forces opens the possibility of a systematic, chemical science, though a science that is improper. The mathematical-mechanical approach, by contrast, cannot give rise to any coherent science of chemistry, due to its dependence on empty concepts.<sup>81</sup>

Furthermore, despite the absence of *a priori* coordination principles between the chemical forces and mathematical constructions, chemistry has quantitative regularities. The principle of the Anticipations of Perception guarantees that one can to ascribe degrees to the qualities of experience (KrV, A166–76/B207–18). So one can assign quantitative measurements to chemically relevant properties, such as reagent weights, specific gravities, and degrees of

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<sup>79</sup> Kant mentions the dissolution of iron by *aqua fortis* in DP (29.163). This example is also found in Newton's *Opticks* (1952: 380f.). The chemical methodology I describe is related to Newton's approach to chemical affinities described in Query 31 of the *Opticks*.

<sup>80</sup> We now understand the reaction between the solution of silver and *aqua fortis* as a single-replacement reaction. Silver (Ag) and *aqua fortis* (HNO<sub>3</sub>) produce silver nitrate (AgNO<sub>3</sub>) as well as water and an oxide of nitrogen. When copper (Cu) is added, the silver in the nitrate is replaced, leaving copper nitrate (Cu(NO<sub>3</sub>)<sub>2</sub>) and a metallic silver precipitate.

<sup>81</sup> Nayak and Sotnak (1995: 149) claim that chemistry would be a proper science were chemical interactions reducible to fundamental forces. This is to misunderstand the fundamental chemical forces. Reduction of *all* chemical interactions to a simple set of chemical forces is an unachievable regulative ideal of reason (see KrV, A642–68/B670–96). But even if this *were* possible, the chemical forces cannot be coordinated via physics with mathematical constructions, as such a coordination requires either the representation of an infinite division (assuming dynamism) or metaphysically incoherent presuppositions (assuming mechanism).



heat.<sup>82</sup> Such quantitative measurability makes possible quantitative regularities in chemistry. For example, one may find in experience that it always takes the same volume of warm water to dissolve one milliliter of saltpeter.<sup>83</sup> Now this does not mean that dynamical chemical concepts have thereby been coordinated with mathematical constructions; there is still no mathematical object that represents the dissolving force of the water. Rather, the principle of the Anticipations merely makes possible the quantitative measurements and judgments that Kant observed in contemporary chemical practice, while the science remains improper.

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<sup>82</sup> So I concur with Körner's claim that the anticipations of perception make possible quantitative measurement in science; further, I take this to be an important observation. However, our considerations have shown that Körner's additional claim—that quantitative measurability of a science's subject matter is all that is necessary for that science to be proper—is false.

<sup>83</sup> This is an example from Karsten's textbook (AKN, 29.313). Karsten explains that one part saltpeter is dissolvable in seven parts of 59° F water.

## CHAPTER 2

### Rehabilitating the Regulative Use of Reason

#### Kant on Empirical and Chemical Laws

Although chemistry is an improper science, it is nonetheless closer to the rank of proper science than, for instance, psychology, natural history, or natural description, which are either doctrines—aggregates of the understanding’s cognitions—or mere sciences—doctrines whose cognitions are systematically interconnected (MAN, 4.467f.). Chemistry, according to Kant, is a *rational* natural science, that is, a science whose cognitions are connected “as grounds and consequents” (4.468). Kant also, seemingly equivalently, claims that chemistry is an “experimental doctrine” (4.471).<sup>84</sup>

This chapter is concerned with those features of chemistry that distinguish it as a rational science. The few commentators who have treated Kant’s conception of chemistry have failed to explain chemistry’s status,<sup>85</sup> and, generally, the topic of the nature and possibility of rational, but improper, science has been inadequately treated by scholars.<sup>86</sup> In this chapter, I explain the possibility of rational science as a unique classification of doctrines, distinct from mere science, on one hand, and proper science, on the other. In section 1, I argue that rational sciences have genuine, empirical, causal laws. I explain, in section 2, that available interpretations of empirical

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<sup>84</sup> I return to the sense in which chemistry is an experimental doctrine below.

<sup>85</sup> For instance, though Friedman has made outstanding contributions to the scholarship on Kant’s philosophy of science, he does not discuss chemistry’s status as a rational science. Furthermore, his understanding of chemistry entails a collapse of the Kantian scientific taxonomy (see below).

<sup>86</sup> Few offer explicit interpretations of rational science. Those that do, such as Plaass (1965), Pollok (2001), and Watkins (1998), either fail to flesh out their accounts or defend views that collapse distinctions in Kant’s hierarchy of the sciences (see below). Other interpretations of Kant’s philosophy of science, despite not explicitly considering the possibility of rational science, similarly entail a collapse of the distinctions in his scientific taxonomy.

lawlikeness and the necessity of empirical laws fail to account for the possibility of rational, but improper science.<sup>87</sup> These interpretations hence misrepresent Kant's views of chemistry, conceptualizing it as a mere science incapable of genuine laws. In section 3, I present an alternative, 'ideational' account of the necessity of empirical laws. According to this account, genuine chemical laws are possible in virtue of the postulation of ideas of pure reason and principles that assert properties of these ideas. Reason's ideas of *elements* are those that necessitate the judgments of chemistry, making laws possible. In section 4, I defend my ideational account of empirical laws from a variety of objections. Finally, in section 5, I describe my interpretation of Kant's claim that chemistry is an experimental doctrine and offer a provisional explanation of psychology's status in the hierarchy of the sciences.

## 1. Rational Sciences Have Empirical, Causal Laws

What distinguishes a science from a doctrine (a mere aggregate of cognitions) is that the former is systematic.<sup>88</sup> Kant presents his conception of systematicity in the Appendix to the Transcendental Dialectic (KrV, A642–668/B670–B696) and the introductions to KU (5.171–198, 20.195–251). Systematicity, for Kant, consists in the logical ordering of concepts into a species-genus hierarchy; the concepts of a system are all interconnected in a great Porphyrian tree. Each pair of concepts has a higher genus under which they fall. Every concept can be differentiated

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<sup>87</sup> Including those of Allison (1994), Buchdahl (1966, 1971), Friedman (1992a, 1992b: 165–201, and 1992c), Guyer (1990a), Kitcher (1986, 1994), and Rush (2000).

<sup>88</sup> See KrV (A832/B860), Log (9.139), and MAN (4.467).

into further species. Conceptual variation is continuous: between any species and its genus, there are intervening concepts.<sup>89</sup>

Conceptual systematicity entails a kind of judgmental systematicity as follows. Judgments are systematized by way of inferences. I consider an example that regards the process of calcination in order to clarify this judgmental systematization. As discussed in the prologue, calcination is a chemical reaction whereby an inorganic substance (especially a metal) heated below its melting point becomes a calx. Such a calx is an ash-like substance with new chemical properties. So, for example, metallic lead, when roasted, becomes a powder (either white or red) with different qualities and reactivities from the lead. The topic of calcination was central to the chemistry of Kant's time and comprises a crucial example in the remainder of this chapter. So, for instance, the judgments "Metals can be calcined" and "Lead can be calcined" can be systematically connected by the following inference.

Metals can be calcined.

Lead is a metal.

Therefore, lead can be calcined.

A science's judgments are systematized insofar as they stand in a hierarchy of inferences; such a hierarchy orders judgments insofar as greater or fewer other judgments of the domain may be inferred from each (KrV, A305/B361). When a science is fully systematized, judgment can be considered to be the consequence of a higher judgment or principle.<sup>90</sup> Ultimately, reason seeks

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<sup>89</sup> The preceding three propositions are titled the principles of homogeneity, specification, and continuity of forms, respectively (KrV, A658/B686). For more on these principles (and, in particular, on the correct understanding of the principle of continuity) see Watkins (2013a: 289–95).

<sup>90</sup> Though, of course, there is an upper limit to the judgmental hierarchy in a system. In an ideal, fully systematic science, there would be a single, fundamental principle from which all the other judgments of the science can be analytically inferred.

fundamental *a priori* principles—judgments that cannot be derived from any others (Log, 9.110)—that logically and really ground the judgments of the understanding (KrV, A307f./B364).

The final systematization of the understanding's cognitions is a regulative ideal. Though there is considerable disagreement about the sense in which systematicity is a regulative ideal, the following can uncontroversially be said. Reason demands that we hierarchically order our concepts and judgments as much as possible, although we can only asymptotically approach this objective (KrV, A644f./B672f.). So no actual, particular body of the understanding's cognitions instances reason's ideal of systematicity, but the goal nonetheless serves as a norm for scientific practice: approximating this ideal is part of scientific methodology.

As I noted above, a rational, natural science is one in which the cognitions of the system are connected as grounds and consequents. In the *Metaphysik Volckmann*, Kant explains that a ground is something such that, if it is posited, something else (the consequent) is posited. The ground-consequent relation comes in two types: logical and real (V-Met/Volckmann, 28.403). A logical ground is one such that, if it is posited, the consequent can be posited logically, that is, according to the law of non-contradiction. According to Kant's conceptual-containment logic, in the case of logical grounding, the consequent-concept is contained in its ground-concept. So, for instance, in the judgment, "If something is a human, then it is an animal," humanity is a logical ground for animality. If humanity is posited of something, then animality is also posited of that thing, as the concept human is analyzed as containing the concepts of rationality and animality. In virtue of conceptual containment, when any concept is posited of something, all concepts

contained therein are also posited. Judgments that assert logical grounding relations are thus analytic.<sup>91</sup>

Logical grounds are distinguished from real grounds. In a real ground-consequent relation, the consequent is posited with the ground, but not according to the law of non-contradiction (i.e., not logically). So a real ground-concept is not conceptually contained the consequent-concept. Kant gives the example, “if in saying that in being chilled I also posit that I will catch a cold, then this is an entirely different concept of being chilled” (V-Met/Volckmann, 28.403).<sup>92</sup> In this case, the ground (being chilled) does not conceptually contain the consequent (having a cold), though the latter is supposed to obtain in virtue of the former. Hence, this is not a logical but rather a *real* ground-consequent relation. After presenting this distinction, Kant explains that real ground-consequent relations just are *causal* relations: “That which contains the real ground for a consequence is called a cause” (V-Met/Volckmann, 28.403).<sup>93</sup>

Watkins (2005: 232–65) has shown that causes and effects are both determinations of substances instead of events, for Kant. Real ground-consequent relations hence connect determinations of substances. So, in the above example, the substance (Kant’s body) has two determinations (being exposed to the cold and having the flu). Neither determination contains the other logically, so they cannot be related as *logical* grounds and consequents, but there is nevertheless a synthetic connection between the two: if the one is posited so too is the other. Consequently, as there is a positing relation between the two determinations and there is no

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<sup>91</sup> This analyticity can be recognized in two ways. First, judgments of logical grounding are defined as those that follow from the law of non-contradiction; all such judgments are analytic (KrV, A151/B190). Second, in a judgment of logical grounding, the subject (logical ground) contains the predicate (logical consequent), meaning the judgment is analytic (KrV, A6/B10).

<sup>92</sup> Translated in Guyer (1987: 250).

<sup>93</sup> Translated in Guyer (1987: 238).

analytic connection between the two, they are connected as real ground (being exposed to the cold) and consequent (having the flu).<sup>94</sup>

In light of this distinction, Kant's claim—that a rational science is systematic and connects its cognitions as grounds and consequents—raises the question of whether a rational science connects its cognitions as *logical* or *real* grounds and consequents. I maintain that a rational science must have real ground-consequent relations.

If rational sciences merely connect their cognitions via *logical* ground-consequent relations, the distinction between rational sciences and mere sciences collapses.<sup>95</sup> A science is a body of concepts that are ordered in a genus-species hierarchy and judgments that are thereby logically unified via inferences made possible by the conceptual systematization. For instance, categorical judgments about S logically imply judgments about concepts under S (that is, any species of S). Then subsequently demanding the interconnection of the cognitions of a science as logical grounds and consequents does not constitute an additional demand on a science. As I noted above, logical ground-consequent relations are merely analytical connections between concepts and judgments. Hence, the requirement that the concepts and judgments of a science are logically systematized would satisfy the condition that its cognitions be connected as logical grounds and consequents. So conceiving of rational sciences as those sciences that connect their cognitions as logical grounds and consequents effectively collapses the science-rational science distinction.

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<sup>94</sup> The real ground for a determination of a substance may be a determination of a *different* substance: for instance, the real ground for a billiard ball's motion after impact may be the motion of a different billiard ball.

<sup>95</sup> Watkins (1998: 568) understands the ground-consequent interrelating in rational science to be equivalent to logical systematization; hence, his view entails this collapse of mere science and rational science.

A *rational* science like chemistry must therefore connect its cognitions as *real* grounds and consequents (see van den Berg 2011: 11-6).<sup>96</sup> But if a rational science's cognitions are causally interconnected, then it must have causal *laws*. However, this requirement raises another serious difficulty. In the *Analytic of Principles of KrV*, Kant famously claims that empirical, causal laws are, in some sense, necessary.<sup>97</sup>

Even laws of nature, if they are considered as principles of the empirical use of the understanding, at the same time carry with them an expression of necessity, thus at least the presumption of determination by grounds that are *a priori* and valid prior to all experience. (KrV, A159/B198)<sup>98</sup>

In order to account for chemistry's status as a rational science in MAN, I therefore must explain how it can include causal laws: necessary connections between real grounds and consequents.

## 2. Against Existing Conceptions of the Necessity of Causal Laws

Kant's account of the necessity of causal laws is unfortunately obscure. That said, he is reasonably clear about some aspects of empirical lawlikeness. First, empirical laws cannot be

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<sup>96</sup> Plaass (1965: 38) and Pollok (2001: 58f.) claim that the 'rational' in 'rational science' refers to rational cognition, that is, cognition from principles (KrV, A836/B864), meaning that rational sciences are those whose cognitions are grounded in principles. I broadly concur with this thesis, although I contend that the rational cognition in rational science is of a special sort. In particular, the principles of a rational science must be causal, not merely logical (a requirement overlooked by Plaass and Pollok). Below I describe the sort of causal principles the lay at the basis of chemistry.

Sturm (2009: 145) recognizes that, in some sciences, the connections of cognitions are logical, and in others they are explanatory or causal. However, he considers these features to be manifestations of the general notion of 'inner systematicity,' overlooking the fact that there are two *different* kinds of systematization (logical and real), associated with different *sorts* of science, for Kant.

<sup>97</sup> See KrV (A193/B238; A646/B674), Prol (4.312), KU (5.184–5). In the Third Antinomy, Kant claims that a cause must be "sufficiently determined *a priori*" (KrV, A446/B474).

<sup>98</sup> The context of the quoted passage potentially causes trouble for my account defended below. After it, Kant suggests that the highest principles of the understanding ground all lower empirical laws (cf. KrV, A127f.; B165). However, as I show in section 2, though the principles of the understanding may very well ground the laws of physics (as Kant argues in MAN), one cannot analogously derive the laws of chemistry from the principles of the understanding. Such a derivation would make chemistry into a proper science. Hence, I suggest that Kant means the claim that laws must be grounded in principles of the understanding to apply only to physical laws. As I argue below, the laws of chemistry (and any rational science), in lieu of their connection to the principles of the understanding, must derive their necessity from another ground: reason's ideas.



derived directly from the categories or the pure principles of the understanding, thus ruling out a straightforward, deductivist interpretation of empirical laws (KrV, A127, B165).<sup>99</sup> Such a direct deduction would easily account for the necessity of empirical laws, as what is deduced from the necessary must, itself, be necessary (KrV, B3). Second, the systematization of the understanding's cognitions—that is, the above-described hierarchical ordering of concepts and judgments—is central to the necessity of empirical laws.

If we survey the cognitions of our understanding in their entire range, then we find that what reason quite uniquely prescribes and seeks to bring about concerning it is the **systematic** in cognition, i.e., its interconnection based on one principle. This unity of reason always presupposes an idea, namely that of the form of the whole of cognition, which precedes the determinate cognition of the parts and contains the conditions for determining *a priori* the place of each part and its relation to the others. Accordingly, this idea postulates complete unity of the understanding's cognition, through which this cognition comes to be not merely a contingent aggregate but a system interconnected in accordance with necessary laws. (KrV, A645/B673)<sup>100</sup>

Although Kant clearly highlights the importance of systematization for empirical lawlikeness, he fails to identify the *source* of the necessity of empirical laws. Scholars have defended a variety of positions on empirical lawlikeness and systematicity. According to Friedman's 'categorical interpretation,' the categories are the ultimate source of the necessity of empirical laws.<sup>101</sup> The systematization of a science only confers necessity by connecting empirical laws to higher, *a priori* laws that are (indirectly) derived from the categories. Various 'system interpretations,' by contrast, hold that systematization plays no mere subsidiary role in the necessitation of empirical

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<sup>99</sup> Butts (1986: 171) observes that were such a derivation possible, it would imply that the categories or the pure principles of the understanding have empirical content.

<sup>100</sup> See also KU (5.179f., 185).

<sup>101</sup> See Friedman (1992a, 1992b: 165–210, and 1992c).

laws.<sup>102</sup> Rather, the hierarchical ordering of empirically-discovered regularities and the approximation of an ideal, final science constitute an *independent* source of necessity.<sup>103</sup>

In what follows, I present and argue against these accounts of the necessity of causal laws. In the next section, I explicate and defend my own ‘ideational interpretation’ of the necessity of empirical, chemical laws, according to which systematization confers necessity onto empirical laws of non-physical sciences, especially chemistry, by connecting them to regulative ideas of unconditioned real grounds. The relevant ideas of chemistry are those of elements, which are postulated *a priori* to make possible chemical explanations. In virtue of their *a priori*, the ideas of the elements suffice to ground the necessity of chemical laws.

In a series of works, Friedman defends a compelling account of empirical lawlikeness in Kant’s Critical corpus. According to Friedman’s categorial interpretation, genuine laws of nature result from successively superadding empirical content to the pure principles of the understanding. For example, in MAN, Kant specifies the principles of the understanding with the (empirical) concept of matter to derive the *a priori* special metaphysical principles of physics (e.g., the mechanical laws). These principles communicate the necessity and universality of the categories to the other laws of physics, like the law of universal gravitation (Friedman 1992c: 80–3). This law results from the application of the principles of physics to empirical regularities,

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<sup>102</sup> Authors defending such a position include Allison (1994), Buchdahl (1966, 1971), Guyer (1990a), Kitcher (1986, 1994), Rush (2000), and Sturm (2009: 127–82). Buchdahl’s and Sturm’s interpretations are hybrid views, also delimiting a role for reason’s ideas (see below). I concur with many of the arguments against system interpretations that appear in Kreines’ (2008) treatment of the topic. However, I also object to Kreines positive account of laws in section 3.

<sup>103</sup> In his recent, illuminating work on Kant’s notions of necessity, Nicholas Stang (2011: 487f.) also takes seriously Kant’s claims that natural laws are necessary, though he offers no positive account. That said, the general constraints he imposes on acceptable accounts of natural laws’ necessity strike me as correct; my ideational account satisfies his demand for a new sort of necessity for lower causal laws.

specifically, Kepler's regularities.<sup>104</sup> Though these regularities are based on induction and hence contingent, the law of universal gravitation is nonetheless necessary and universal in virtue of resulting from an application of the *a priori* principles of physics (Friedman 1992a: 173f.).<sup>105</sup>

For Friedman, the *a priori* core of physics, derived from the categories, is the foundation for necessary, empirical laws. A natural science, according to the categorial interpretation, admits of genuine empirical laws only insofar as its laws can be (indirectly) derived from the special metaphysical principles of physics: it is only in virtue of such a derivation that laws can inherit the necessity of the pure principles of the understanding. Kitcher (1994: 258) complains that the categorial interpretation thus rules out the possibility of genuine, non-physical laws (e.g., chemical laws). Although Friedman recognizes this implication of his interpretation, he dismisses any shortcoming (1992a: 188–91, 2013: 241),<sup>106</sup> because he thinks that when Kant denies chemistry the status of a proper science in MAN (4.468, 471), he thereby implies that it is incapable of laws. Friedman takes this to be due to the fact that chemistry cannot be reduced to physics. So the purported 'laws' of chemistry are mere inductively-justified regularities and are not necessary: they are therefore on par with empirical regularities.<sup>107</sup>

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<sup>104</sup> The transition from Kepler's regularities to Newton's law of universal gravitation is Friedman's exemplar for the emergence of genuine, necessary laws; see (1992a: 175–80, 1992b: 174–7, and 1992c: 84f.).

<sup>105</sup> Vanzo (2012: 85–9) supplements Friedman's picture with an account of and role for experimentation. He argues that, for Kant, experimentation is a necessary though insufficient condition for genuine laws of nature. The judgments justified by experimentation can only become laws through their integration into a system of *a priori* laws grounded by the principles of pure reason and the principles of special metaphysics. The latter systematization necessitates empirical laws. Though Vanzo emphasizes experimentation (and shares this emphasis with my interpretation: see section 3), his account of the *necessity* of empirical laws is ultimately no different from Friedman's.

<sup>106</sup> Allison (1994: 305), despite advancing criticisms of Friedman's interpretation, agrees with him that chemistry is incapable of genuine laws. Vanzo (2012: 86n.) also concurs.

<sup>107</sup> I agree with Friedman's contention that chemistry would be proper, if it were reduced to physics. But, *pace* Friedman, reduction is not the *only* route to chemistry's propriety. Were the laws of chemistry mathematically constructible (independently of the constructibility of physics' laws), the science would be proper: see chapter 1.

However, there are substantial problems with the categorial account. First, Kant regularly refers to *laws* (*Gesetze*) and *principles* (*Grundsätze, Principien*) in chemistry.<sup>108</sup> And in KpV Kant makes clear that chemistry has laws, though its laws are of a different sort than those of physics.

Even the rules of uniform appearances are called laws of nature (e.g., mechanical laws) only when they are either cognized really a priori or (as in the case of chemical laws) when it is assumed that they would be cognized a priori from objective grounds if our insight went deeper. (KpV, 5.26)

Now, while the difference between chemical and physics laws is opaque at this point,<sup>109</sup> Kant obviously maintains the existence of chemical laws; to claim that chemistry admits only of mere empirical regularities is in conflict with his stated views. Second, the categorial interpretation effectively collapses the distinction between rational sciences (those capable of laws) and proper sciences (those capable of *a priori*, apodictically certain laws) drawn by Kant in the opening pages of MAN (4.468). For Friedman, a science only has laws when they are connected to the *a priori* ground derived from the categories. But Kant claims that rational sciences have causal laws and that their laws *can* be grounded *empirically*, as in chemistry. Empirically grounded laws preclude the *propriety* of a science, yet such laws *are possible* in a rational science. To account for the possibility of rational science as a distinct classification of natural science, I must provide a different account of empirical lawlikeness.

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<sup>108</sup> In MAN, Kant writes of chemical laws (4.468, 534) and chemical principles (4.469, 471). In the General Remark to the Dynamics, he also discusses the discovery of laws regarding “matter’s inherent forces” (MAN, 4.533); a subset of these forces is the chemical (MAN, 4.530; OP, 21.453). Finally, throughout the opening passages of DP, Kant claims that there are chemical laws and principles (29.97–9).

<sup>109</sup> The counterfactual claim made by Kant in this passage—that we could cognize *a priori* laws, if our insight went deeper—is explicated in section 4.1.

System interpretations emphasize that the necessity of empirical laws essentially involves the process of systematization discussed above.<sup>110</sup> Although a diversity of accounts of empirical lawlikeness stress systematization, they share a common interpretive core. System interpretations are based on the thought, expressed in the above passage from KrV (A645/B673), that interconnecting empirical regularities in a *system* is what makes them into necessary laws.

As I suggested above, Friedman believes that systematization plays only an auxiliary role in securing the necessity of empirical laws (1992c: 89): systematization necessitates laws by (indirectly) connecting them to the principles of the understanding. On system interpretations, by contrast, systematization is an *independent* source of necessity. The driving idea behind these interpretations is that empirical laws are necessary to the extent that they can be derived from more general laws in a science: systematization makes such derivations possible.

Kitcher claims that it is the approximation of the ideal systematization of our beliefs that confers necessity on empirical laws. For Kitcher, “Laws are statements that play a particular role in the system that would emerge from an ideally extended inquiry” (1986: 215). So the necessary laws are those that belong to the ultimate, final science. As we systematize our cognitions, those judgments that persist are hence regarded as lawlike. Fred Rush defends a similar interpretation of necessity of empirical laws. He explains that the laws of a *complete* system of nature—the unreachable goal of reason—would be necessary in virtue of the system’s exclusivity (Rush 2000: 847). As a doctrine of nature approaches completion, it rules out more competitive theories, nears exclusivity, and hence its laws seem more necessary. Yet, as Rush admits, there is

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<sup>110</sup> Buchdahl’s (1966, 1971) understanding of empirical lawlikeness is the first and most influential system interpretation. He argues that an empirical law is necessary when it is the component of a constructed, systematic theory (1966: 216f., 1971: 32). But Buchdahl further alludes to the idea of systematicity as being the *ground* for the necessity of systematized laws. This suggestion, though inspirational for my alternative, ideational account, is inadequately fleshed out in Buchdahl’s works. As I argue below, an interpretation that centrally features ideas of reason avoids many of the problems facing system interpretations.

scant textual evidence for these interpretations. Furthermore, Kant claims that there must be *a priori* grounds for the necessity of empirical laws (KrV, A159/B198; KU, 5.179f.). But neither Kitcher's nor Rush's interpretation provides such *a priori* foundation for empirical laws.<sup>111</sup>

Guyer claims that an empirical generalization is contingent in isolation. Nevertheless, it will *appear* necessary when embedded in an inferential network, in which the generalization is entailed by higher principles and verified by judgments standing under it (Guyer 2003: 287f.).<sup>112</sup> But it is unclear how increasing the inferential density of a body of cognitions will grant *necessity* to the judgments of the doctrine. Verification by lower, entailed judgments could only inductively justify the generalization. Its entailment by higher judgments would only necessitate the generalization in the case that these higher judgments are, themselves, necessary. Without explicitly presenting such *a priori* grounds for empirical laws, Guyer's interpretation fails to illuminate the necessity of empirical laws.

A deep difficulty confronts system interpretations of the necessity of empirical laws. By claiming that mere logical systematicity gives a science genuine laws, the systematizer has effectively collapsed the science-rational science distinction. As I noted above, what distinguishes a rational science from a mere science is that the former has causal laws *in addition*

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<sup>111</sup> Following Buchdahl, Kitcher or Rush may claim that the very idea of systematicity is the requisite *a priori* foundation for empirical laws (however, neither explicitly does so). But, as I noted in the preceding footnote, no scholar has presented a plausible, coherent account along these lines, and it is furthermore difficult to imagine how such an account could succeed. If laws are only necessary in a genuine system, then, since systematicity is an ideal that we can only approximate, no actual body of cognitions can achieve this necessity. There is also no evidence for the claim that laws become 'more' necessary as we approximate systematicity. Rather, the textual evidence from KrV, considered below, suggests that we can discover necessary laws one by one through experimentation and the hypothetical use of reason. Hence, below I argue that the basic ideas of causal powers of a natural science, themselves *a priori*, ground the necessity of that science's laws (and *not* the general idea of systematicity, itself). Along similar lines, Sturm (2009: 158) claims that the principles of systematicity make possible causal explanations in science, yet he fails to explain how the principles could necessitate the laws of a rational science: see below.

<sup>112</sup> In a note to this passage, Guyer (2003: 295) approvingly cites Rush as an ally.

to the latter's systematicity. To collapse these conditions is to thus conflate science and rational science.

Interpretations that ground the necessity of empirical laws on the categories collapse the distinction between proper science and rational science; interpretations that ground the necessity of laws on the mere logical ordering of a science collapse the distinction between mere science and rational science. To avoid this dilemma and to account for the possibility of rational science as a distinct classification of natural science, a different ground for the necessity of empirical causal laws is required.

### 3. The Necessitation of Empirical Laws by the Ideas of Reason

On my alternative, ideational account, ideas of reason and principles asserting the essential features of these ideas constitute the ground for genuine, empirical laws of rational sciences such as chemistry. Like Friedman's interpretation but in contrast to the system interpretations my account contends that genuine laws require *a priori* grounds. But my interpretation diverges from Friedman's insofar as I contend that reason's ideas—and not just the understanding's categories and principles—can constitute such an *a priori* ground, making possible real ground-consequent relations and genuine empirical laws.

Such foundational, scientific ideas are produced through the hypothetical use of reason, which is depicted in the Appendix to the Transcendental Dialectic in contrast with the apodictic use of reason.<sup>113</sup>

If reason is the faculty of deriving the particular from the universal, then: Either the universal is **in itself certain** and given, and only **judgment** is required for

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<sup>113</sup> The hypothetical and apodictic uses of reason of KrV become, respectively, reflective and determinative judgment in KU.

subsuming, and the particular is necessarily determined through it. This I call the “apodictic” use of reason. Or the universal is assumed only **problematically**, and it is a mere idea, the particular being certain while the universality of the rule for this consequent is still a problem; then several particular cases, which are all certain, are tested by the rule, to see if they flow from it, and in the case in which it seems that all the particular cases cited follow from it, then the universality of the rule is inferred, including all subsequent cases, even those that are not given in themselves. This I will call the “hypothetical” use of reason. (KrV, A646f./B674f.)

Here Kant generally describes reason as the faculty of connecting the particular and the universal; by this he means that it is the faculty of *inference* (KrV, A300/B357).<sup>114</sup> Reason connects the particular judgment with a rule or principle (the universal) by inferring the former from the latter. There are two initial conditions for the employment of reason: either the particulars are given and one seeks the universal, or the universal is given and one seeks the particulars. One uses reason *apodictically* when one seeks particulars that can be inferred from a given and certain rule. As an illustration, consider the given rule “Humans are mortal.” The apodictic use of reason derives particular judgments from this rule—“Socrates is mortal,” “Ludwig Wittgenstein is mortal,” and so on—by means of mediating judgments that assert the condition of the principle (humanity) of those individuals (KrV, A321f./B378).<sup>115</sup>

The *hypothetical* use of reason transitions from a particular judgment to a principle from which the judgment in question follows. So, for instance, given the judgment “Humans are mortal,” the hypothetical use of reason seeks a rule or universal from which the given judgment can be inferred. For instance, one may propose the judgment “Animals are mortal” as the rule

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<sup>114</sup> Surprisingly and unfortunately, few commentators connect Kant’s consideration of the regulative use of reason to his description of the faculty of reason at the beginning of the Dialectic. Exceptions include Grier (1997), Morrison (1989), and Wartenberg (1979, 1992). Failing to make this connection can lead to substantial confusions: see the note below on Rauscher’s interpretation.

<sup>115</sup> The middle term of the syllogism is a *condition* for the major term. For instance, due to the above inference, Wittgenstein’s humanity is the *condition* of his mortality. A helpful discussion of reason’s logical use can be found in Rohlf (2010).



from which “Humans are mortal” can be inferred through the mediating judgment “Humans are animals.”

Although this use of reason allows for the logical systematization of a science (as in the above example), it also allows for the discovery and postulation of real, causal grounds for the judgments of an empirical science.<sup>116</sup> To unify the cognitions of a science under fundamental causal powers, higher principles are sought, from which the empirical regularities of the science may be inferred. So, for instance, one may begin with the judgment “Lead can be calcined,” an empirical regularity derived from repeated observation. By means of the hypothetical use of reason one seeks a rule that asserts that another of lead’s determinations is the real ground for its calcinability. Yet *prima facie* it is not clear which property of lead is such a condition: any of lead’s determinations could be the ground for its calcinability. It could be in virtue of lead’s color or malleability, for instance, that it is calcinable. At this juncture, the hypothetical use of reason offers us no counsel. One may *hypothesize* whatever determination one wishes as the ground for calcinability.

Lead’s color, for instance, may be postulated as the condition of its calcinability. One then postulates the rule “Gray substances can be calcined,” from which lead’s calcinability is deducible by the minor premise “Lead is gray.” Now, according to the hypothetical use of reason, this rule is “assumed only **problematically**.” While the given judgment “Lead can be calcined” is taken as certain, the rule that declares grayness to be the condition of calcination is merely assumed as the ground for the given judgment. That is, the *universality* of the rule still is a *problem* for reason, to be confirmed or disconfirmed.

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<sup>116</sup> Guyer (1990b: 22–5) recognizes the parallel distinction between logical and explanatory regulative ideals of reason.

As Kant claims, the rule is tested with particulars “to see if they flow” from the rule. That is, the scientist experimentally determines whether those judgments that follow from the rule are true. She may test whether ashes, which are gray, can calcine. She would, of course, find that the ashes do not calcine, although the judgment that ashes are calcinable follows from the rule that “Gray substances can be calcined.” Therefore, the rule is *not* universal, and grayness is not the real ground for calcinability.

Undeterred, reason demands the postulation and testing of other rules to unify the judgments of, e.g., calcination. For instance, one may hypothesize that lead’s property of being a metal is the real ground for its being calcinable. Again, the scientist would experimentally test this rule. This time, it turns out that all metals are calcinable. For instance, when heated, copper, iron, and mercury become powders with different chemical properties as before.<sup>117</sup> So the scientist has at least confirmed that everything falling under the condition of being a metal has the property of being calcinable. This time, she has better unified calcination phenomena.

There are, however, substances that are *not* metals that can be calcined. For example, limestone, when heated, produces quicklime.<sup>118</sup> This process does not falsify the rule “Metals are calcinable.” But it does show that the property of being a metal is *not* the condition or real ground of calcinability. Reason, generally, seeks absolute conditions for given judgments (KrV, Bxx; A322–326/B379–383).<sup>119</sup> In this context, reason will only be satisfied with the ultimate

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<sup>117</sup> Note that the processes of dissolving silver or gold in a strong acid (*aqua fortis* or *aqua regia*) were thought to be a kind of calcination by alchemists and early modern chemists. Wallerius distinguishes calcination by fire and calcination in a menstruum (1761: 151ff.).

<sup>118</sup> Indeed, the name ‘calcination’ comes from this process.

<sup>119</sup> Cf. KrV (A307f./B364). There Kant claims that there is a logical principle of reason—that we seek the conditions of the cognitions of the understanding via prosyllogisms—and a transcendental principle—that the unconditioned is itself given with the conditioned.

ground for calcination: a property had by those and only those substances that can be calcined.<sup>120</sup>

So the rule that metals can be calcined, though it unifies judgments that assert the calcinability of a specific metal, does not adequately systematize all particular judgments of calcination.

No property that unifies all calcination phenomena is forthcoming in experience. So reason, in order to satisfy its own need for the unconditioned condition, advances an idea, *phlogiston*, as the bearer of the property of calcinability.<sup>121</sup> An idea, for Kant, is a concept postulated by reason in order to unify the cognitions of the understanding, though it is ultimately beyond the possibility of experience (KrV, A310f./B367f.).<sup>122</sup> Phlogiston, along with the other elements, “as far as their complete purity is concerned, have their origin only in reason” (KrV, A645f./B673f.).<sup>123</sup> For Kant, each element is posited as a pure carrier of a certain causal power (DP, 29.161): each element is assumed to be the real ground for an observed, material determination.<sup>124</sup> (Kant hence adopts the *power* conception of the elements, see the prologue.) This purity allows phlogiston, for instance, to be the absolutely unconditioned condition for calcination. Since phlogiston *just is* the bearer of the property of calcination, it has no other

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<sup>120</sup> Watkins (2013a: 293) explains that real grounding or causal relations are conditioning; hence they are relations for which reason seeks unconditioned conditions.

<sup>121</sup> Kant takes phlogiston to be an element; see DP (29.161, 163) and Refl 45 (14.371–396). In KrV, Kant writes of reducing all chemical behavior to pure substances, including “combustibles” or “inflammable beings” (*brennliche Wesen*) (KrV, A646/B674). Here, again, Kant means to refer to phlogiston.

<sup>122</sup> For Kant, there are *transcendental* ideas of reason—God, freedom, and immortality—that arise from the three syllogistic forms: the transcendental ideas are the unconditioned conditions for the *totality* of judgments related by such syllogisms (KrV, A321f./B377–9). Lower ideas of reason—like those of the elements—are postulated as the grounds for the unification of limited aggregates of the understanding’s cognitions (like judgments of, say, calcination or acidity).

<sup>123</sup> Kant calls elements “fundamental concepts of reason” in Refl 45 (14.375).

<sup>124</sup> This conception of the elements fits with chemical practice contemporaneous with Kant; see section 4.2.

properties that could serve as *further* grounds for calcinability.<sup>125</sup> The individual empirical regularities—lead can be calcined, iron can be calcined, limestone can be calcined, etc.—are unified in that the presence of phlogiston explains each.<sup>126</sup>

Unification and experimentation do not end with the postulation of phlogiston. The chemist may note that the calcination process (inorganic substance + fire → calx) resembles the combustion process (organic substance + fire → ash), and so she may further unify the judgments of her science by postulating that phlogiston is the bearer of *inflammability*. All phenomena of combustion and calcination are explained by the presence (and expulsion) of phlogiston. One thus hypothesizes a new principle: ‘Phlogiston is the bearer of inflammability.’ As before, the scientist tests the universality of this principle through experimentation to determine if the particular judgments regarding inflammability actually “flow” from the rule. Now the judgments that, e.g., metals can be calcined, clearly must follow from the rule, as

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<sup>125</sup> At this point, one may worry that phlogiston appears to lack explanatory power insofar as it is simply postulated as the bearer of the property it is meant to explain. In section 4.2, I address this concern.

<sup>126</sup> I thus object to Rauscher’s (2010) conception of reason and its implications for chemical practice. Rauscher argues that systematization is a source of ideas that is independent of Kant’s characterization of reason from the introduction and first book to the *Dialectic*. He claims that in a science, if we find a ‘gap’ in our conceptual hierarchy—a missing genus or species—we may postulate an idea that fills this space. These ideas are *mundane*, meaning that we may find, in experience, a concept that is adequate to filling the gap. For Rauscher, scientific practice is the search for such empirical, gap-filling concepts.

Rauscher significantly misunderstands Kant’s conceptions of reason, ideas, and scientific practice. First, Rauscher’s account entails a bifurcation of theoretical reason. There is, for him, the reason that engages in reverse syllogistic reasoning as depicted at the outset of the *Dialectic*, and the reason that fills gaps in scientific theories in the Appendix. I claim that this division is unnecessary and only muddies the waters. According to my account, one and the same reason unifies all cognitions of the understanding by connecting universal rules and principles with particular judgments (seeking the unconditioned). Second, ideas of reason, by their very nature, cannot be instanced in experience. Kant is clear that ideas are beyond the possibility of experience. To say that there are *mundane* ideas that may be found to have empirical instances is nonsensical. I hence concur with Wartenberg’s (1992: 229f.) conception of scientific ideas as *theoretical* (beyond the possibility of experience). We may certainly search for further empirical *concepts* to fill out our conceptual hierarchies; indeed such a search is legislated by the regulative principles of reason. But ideas are fundamentally beyond the possibility of experience. Theoretical ideas in science serve only to unify the cognitions of that science; this *unification* can then be tested in experience via experimentation. See my description of Stahl’s experiment, below.

phlogiston was postulated as the real ground of calcination. The interesting tests of the rule regard combustion. For example, the scientist must test inferences such as the following.<sup>127</sup>

Phlogiston is the bearer of inflammability.

Charcoal contains phlogiston.

Therefore, charcoal is combustible.

To determine whether the judgment that charcoal is combustible flows from the fact that phlogiston is the bearer of inflammability, we must know whether phlogiston is the *real ground* for the combustibility of charcoal. But we are then faced with an apparent difficulty. How can we determine whether there is phlogiston in the charcoal, if phlogiston is an idea of reason and thus not a possible object of experience? Enter Georg Stahl.

As I noted in the introduction, in the B-preface of KrV, Kant praises Stahl alongside Galileo and Torricelli for putting science on its “secure path,” noting that Stahl “changed metals into calx and then changed the latter back into metal by first removing something and then putting it back again” (KrV, Bxii–xiii).<sup>128</sup> This is a reference to Stahl’s notable (apparent) verification of his phlogiston theory of combustion (see the prologue).<sup>129</sup> In this experiment, Stahl first calcined lead to produce lead calx, which removes the phlogiston from the lead. Next, he burned charcoal in the presence of the lead calx. He then discovered that the metal had

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<sup>127</sup> Note that just because phlogiston’s grounding of inflammability phenomena can be explicated in a logical inference does not mean that it is a mere *logical* ground. One could create similar syllogisms for other cases of real grounding. For instance, one could derive Kant’s having the flu from his being exposed to the cold along with the additional judgment that if one has been exposed to the cold, one will have a flu.

<sup>128</sup> Kant also mentions Stahl as the discoverer of phlogiston in DP (29.163).

<sup>129</sup> See Stahl (1718: 119f.). Erxleben describes the calcination and reduction of lead according to Stahlian principles (1775: 309f., 436ff.). Karsten refers briefly to this process as demonstrating the identity of the burnable substance in metals and plants (29.287f.). Partington (1961–70: 2.670f.) gives a short description of this experiment; see also Carrier (2001: 217f.). The above description of unifying combustion phenomena under the principle of calcination follows the historical progression: see the prologue.

revivified in the course of this process, producing a sample of lead with its characteristic properties restored. This experiment demonstrates that the same thing that left the lead during calcination is absorbed by calx during the combustion of the charcoal. The “something” that Kant reports Stahl “removed” and “put back” is *phlogiston*. That the calx revivifies during the combustion of the charcoal shows that the charcoal releases phlogiston during combustion.<sup>130</sup> Thus, the particular case has been confirmed: that charcoal is combustible depends on the presence of phlogiston. That said, there are innumerable other deductive consequences of the rule that involve combustion. We cannot know that each particular judgment regarding combustion and calcination flows from the rule for we cannot test them all: “this use of reason is only regulative, bringing unity into particular cognitions as far as possible and thereby **approximating** the rule to universality” (KrV, A647/B675). That is, after experimentation, we assume the rule to hold in every case: that phlogiston unifies calcination and combustion phenomena. Stahl, himself, extended the domain of phlogiston, arguing that the principle of phlogiston unifies the animal, vegetable, and mineral realms (1718: 36; 1734: 184).

This example shows how “we question nature according to [our] ideas” (KrV, A645/B674). The ideas and principles of reason allow us to craft principles whose universality can be tested, so that we may be “instructed by nature not like a pupil [...] but like an appointed judge who compels witnesses to answer the questions he puts to them” (KrV, Bxiii). On a similar understanding of experimentation, Wartenberg claims that Kant defends a hypothetico-deductive model of scientific practice (1979: 410f.); I concur with this sentiment. According to my account, observation and induction can only achieve mere empirical regularities. To learn of the

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<sup>130</sup> According to the present-day understanding of this reaction, the carbon monoxide produced as the charcoal burns combines with the oxygen of the lead oxide to produce carbon dioxide, leaving metallic lead.

laws of nature, we must rather demand answers of nature by formulating principles and crafting artificial scenarios to test them.<sup>131</sup>

We thus have produced a principle under which all chemical judgments involving inflammability stand.<sup>132</sup> Furthermore, after its verification, this principle is considered as necessary by reason.

But if one attends to the transcendental use of the understanding, it is evident that this idea of a fundamental power in general does not function merely as a problem for hypothetical use, but pretends [vorgebe] to objective reality, so that the systematic unity of a substance's many powers are postulated *and an apodictic principle of reason is erected*. (KrV, A650/B678; my italic emphasis)

As Kant reports in this passage, an unconditioned principle is to be used *apodictically*. That is, ultimate principle achieved though the hypothetical use of reason, whether it regards cognitive capacities of the mind or inflammability phenomena, serves as the necessary, inferential ground for the other judgments of the relevant science. These principles are necessary for the following reason. The subject of such a principle (like phlogiston) is an idea in virtue of its being unconditioned; ideas, for Kant, are *a priori* (KrV, A320/B377).<sup>133</sup> The judgment that asserts the characteristic quality of an idea (like the phlogistic principle) is likewise *a priori*. But, according to Kant, *a priori* principles are strictly universal and necessary (KrV, B4). Ideas like that of phlogiston are capable of such universality and necessity in virtue of their being objects' being unconditioned. Hence, the fundamental principles of the real grounds of chemistry are universal

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<sup>131</sup> That said, Wartenberg does not address the issues surrounding empirical lawlikeness. Elsewhere, Wartenberg (1992) focuses on the status of theoretical ideas used in science and the transcendental principles of systematicity. Though I agree with the broad strokes of his interpretation, he misses the crucial role that ideas of reason play in the necessitation of empirical laws.

<sup>132</sup> Phlogiston's unification of chemical phenomena does not end here. Phlogiston is also the principle of electricity (DP, 29.161f.) and fermentation (Chang, 2002: 43, 45f.).

<sup>133</sup> Kant also repeatedly claims that reason's systematization of the understanding's cognitions—which ideas make possible—is *a priori* (KrV, A302/B359; A645/B673).

and necessary in virtue of their being ideational. From the judgment that phlogiston is the bearer of inflammability, we can deduce that metals are calcinable in the same sort of syllogisms that we earlier considered hypothetically, which then secures the necessity of these lower judgments. The judgment that tin is calcinable, for example, is originally inferred inductively from a finite class of observations; this means that it has only a relative or approximate universality. The postulation of phlogiston allows for the derivation of the judgment from the principle that phlogiston is the bearer of inflammability. As metals are phlogiston-salt dyads and tin is a metal, any particular sample of tin *necessarily must* be calcinable. The derivation of a judgment from the phlogistic principle rules out the possibility of exceptions, making the judgment strictly universal: to contain phlogiston *just is* to be inflammable.<sup>134</sup> All such particular judgments—that charcoal is combustible, that lead is calcinable—are necessary in virtue of being consequences of the fundamental phlogistic principle.<sup>135</sup> To clarify my position, it must be distinguished from system interpretations. According to the latter, logical systematization is an independent source of necessity for empirical laws. However, my ideational account holds that the necessity of empirical laws is a consequence of reason's postulation of unconditioned real grounds for observed phenomena.<sup>136</sup>

In this sense, such ideas and ideational principles of reason constitute the *a priori* basis that makes possible empirical laws of rational science. The judgments of a science become

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<sup>134</sup> These judgments are not *epistemically* necessary, because they are not conditions of the possibility of experience. They are therefore not necessary from the perspective of the understanding (KrV, A218/B266). For more on the necessity of such laws, see section 4.3.

<sup>135</sup> Because such principles concern ideas of reason, they cannot be *known*: see section 4.1.

<sup>136</sup> Kreines (2008) claims that a true casual law identifies a kind whose nature necessitates a regularity, although he unfortunately misidentifies the kinds that could effect such necessitation: only the ideas of reason can make possible such strictly universal, non-accidental uniformities. He presents the example of salt as an appropriate kind that can necessitate regularity (2008: 532), though Kreines fails to observe that salt is an element, an idea of reason, for Kant. That elements are ideas is the true ground for their necessitation.



strictly universal and necessary in virtue of their derivability from ideational principles. This case is analogous to those that appear in morality. Just as the idea of an ideal model of virtue makes judgments of moral worth possible (KrV, A315/B372), the idea of phlogiston makes possible strictly universal *laws* of combustibility and calcination.

The possibility of laws regarding other chemical properties and phenomena depends upon other ideas of reason.

It is notable, that although the entire world speaks of pure fire, water, air, etc., one still must admit that nothing is pure. Hence, we see that we have mere effects in us, which we refer to matters and in this consideration we name them pure. Our reason makes certain divisions which precede experience and after which we then order our experience. [...] In nature, one cannot go through the differences of things in such a way that one could determine everything, rather one must follow the division of the understanding, [a division] that is necessary so that it happens according to general rules. The earths are the *Onus*, the negative matter that has no dissolving power but rather is to be dissolved. Salt and combustible things [phlogiston] are the pair of *Potentiae* in nature that dissolve everything. [...] Salts need water as vehicle in order to act as potentials, and inflammable beings require the elementary fire as vehicle to dissolve earth—inflammable beings are thereby dissolved. (DP, 29.161).<sup>137</sup>

Just as we postulated phlogiston as the bearer of a particular causal power, we hypothesize other pure elements—earth, salt, water, and air/fire<sup>138</sup>—as bearing or as mediating other chemical powers. I noted above that in virtue of the elements' purity, they are ideas of reason.<sup>139</sup> These

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<sup>137</sup> See also: the very similar passage in KrV (A645f./B673f.).

<sup>138</sup> In KrV (A645f./B673f.), Kant claims that air is the medium for the combustible (phlogiston). As can be seen above, in DP, Kant replaces air as an element with fire, now claiming that “[a]ir is not an element” (DP, 29.162). Carrier (2001: 221) offers the highly plausible hypothesis that when composing KrV, Kant was not up-to-date with then-current chemistry. When preparing for his 1785 physics lectures, Kant likely acquainted himself with developments such as the pneumatic chemists' isolation of new kinds of air. The proliferation of different types of chemically active gases likely pushed Kant to reject the old view of air as an element.

<sup>139</sup> Okruhlik objects to the claim that elements are beyond the possibility of experience, arguing that the existence of, say, pure earth “does not appear to violate the bounds of possible experience in the same way that the hypostatization of absolute space does” (1986: 312). But Kant is clear that the elements are ideas and are *ipso facto* beyond the possibility of experience. If Okruhlik wants to hold onto the idea that one can still have experience of elements, she must then adopt the mundane ideas of Rauscher, to which I object strenuously (see above). To further

elements and the ideational principles that describe the elements' characteristic features make possible laws regarding chemical reactions and properties in general. The elements are the logical and explanatory basis for all of chemistry.<sup>140</sup> As I explained in chapter 1, chemistry studies the chemical forces, those that explain the dissolution and decomposition of substances. For Kant, each of these chemical forces is explained by a correlative element; the elements just are the bearers of the forces of dissolution and decomposition. When the chemist witnesses a new chemical phenomenon, she seeks out its grounds via the hypothetical use of reason, aiming to reduce the phenomenon to an elemental explanation. The ultimate, regulative goal is to explain all chemical phenomena with the parsimonious explanatory basis of the elements. This is how chemistry can be a *rational* science, one capable of real ground-consequent judgments, without being a proper science, one with apodictically certain laws and in which mathematics is applied. The elements, ideas of reason that are produced by means of the hypothetical use of reason, constitute the *a priori* grounds that make genuine chemical laws possible.<sup>141</sup>

Friedman (2013: 252f.) argues that, for Kant, elements—as surrogates for causal powers—are unnecessary in chemistry. Rather, one need only appeal to the fundamental forces

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support my claim, note that the elements are beyond the possibility of experience because they are hypostatizations of fundamental, unconditioned causal powers (and not merely because they are unadulterated).

<sup>140</sup> See section 4.2, below. Sturm concurs that empirical investigations in chemistry require the antecedent postulation of elements (2009: 156f.). Nevertheless, he claims that the principles of the systematicity—those of homogeneity, specification, and continuity—constitute the ultimate basis for causal explanation in a science (2009: 158). I agree that these maxims are important for *motivating* our search for causal and logical foundations of science, but Sturm underestimates the importance of the lower-level ideas of causal powers. As I explain, ideas of causal powers—like those of the elements—necessitate the genuine laws of rational sciences via deductions (see above: an apodictic use of reason is founded on the basis of an idea of a fundamental causal power). Sturm fails to explain how the high-level ideas of systematicity could yield the necessity requisite for causal laws.

<sup>141</sup> I should also note that this interpretation makes sense of the above-cited passage from the General Remark to the Dynamics (MAN, 4.534). In this passage, Kant claims that we cannot comprehend the original forces—those that explain the specific variety of matter—*a priori*, but only postulate a simple set of forces and reduce phenomena thereto. I contend that in this passage, Kant means to claim that in chemistry we can only reduce phenomena to the elements postulated by reason (as the bearers of powers), although we cannot cognize them.

of attraction and repulsion to account for chemical interactions (via hydrostatics). Although Friedman's interpretation is intriguing and draws interesting connections amongst Newtonian, Stahlian, and Eulerian practice, I find little textual support for this thesis. There are a few reasons for prefer my interpretation of Kant's views on chemical practice. First, as we have seen in passages KrV and DP, Kant describes elements as bearing certain causal powers and describes chemical practice as involving the reduction of chemical behavior to the elements. Second, Kant writes regularly of chemical, dissolving, and decomposing forces as sorts of forces distinct from the fundamental forces of attraction and repulsion, especially in the General Remark to the Dynamics of MAN.<sup>142</sup> Third, Kant explicitly defines chemistry in terms of forces, as I explained in chapter 1. Fourth, according to my interpretation, Kant is adopting the dominant chemical paradigm of the time, which was endorsed by the chemist that receives high praise in the B-preface to KrV, Stahl (see below, section 4.2).<sup>143</sup>

#### 4. Objections and Replies

There are three challenges that face my ideational account of empirical lawlikeness. First, in placing judgments regarding ideas of reason at the basis of empirical science, it appears that my interpretation is committed to knowledge beyond the bounds of experience. Second, ideas of

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<sup>142</sup> Other descriptions of dissolving and decomposing forces can be found in chapter 1.

<sup>143</sup> Friedman (2013: 254–7, 550–561) also suggests that the chief regulative goal of chemistry is the extension of its explanations to smaller and smaller spaces. Though I agree that the extension of a doctrine or science to all spaces, however large or small, the exclusive focus on this regulative ideal obfuscates Kant's conception of chemistry. Guyer (1990b: 19–24) helpfully distinguishes three kinds of regulative ideals in Kant's KrV: the ideals of extending a doctrine's application to all spaces, of linking the concepts and judgments of a doctrine to a minimal explanatory basis, and of logically interconnecting a doctrine's cognitions. Friedman's focus on the spatial ends of chemistry has the potential to mislead, for his account inadequately treats chemistry's explanatory and logical systematicity. Indeed the two places where Kant discusses regulative ideas in chemistry, he isolates the elements as constituting the causal or explanatory basis for the science (KrV, A645f./B673f.; DP, 29.161f.). This suggests that the central regulative goal of chemistry is the unification of chemical phenomena according to this basis.

reason may seem explanatorily void, no better than occult powers. Third, by accounting for empirical laws' necessity, my account appears to collapse the distinction between *a priori* and empirical laws.

#### 4.1. Theoretical Belief Beyond the Possibility of Experience

Judgments regarding the elements or any other ideas of reason refer to concepts beyond the possibility of experience. By placing such judgments at the foundation of empirical science, it might appear that my reading transgresses the limits of legitimate knowledge established in KrV. Kant, of course, denies knowledge beyond the bounds of experience, devoting a significant portion of the Transcendental Dialectic of KrV to displaying the problems associated with transcending these boundaries.

Admittedly, the chemical principle discussed above—that phlogiston is the bearer of inflammability—cannot be *known* for just this reason: phlogiston is beyond the possibility of experience. Nonetheless, one can legitimately *believe* the principle. Kant “had to deny **knowledge** in order to make room for **belief** [*Glaube*]” (KrV, Bxxx),<sup>144</sup> meaning that beliefs regarding the supersensible can be legitimate, even if knowledge is not. ‘Belief’ and ‘knowledge’ are technical terms for Kant. One *believes* when one assents to a judgment with sufficient subjective grounds but insufficient objective grounds, while one *knows* when one assents with sufficient subjective and objective grounds (KrV, A823/B851). Chignell (2007: 325–31) understands this to mean that believing requires the subject to have accessible grounds on which one bases one’s assent, while knowing additionally requires that the subject’s ground for belief makes the assented-to judgment probably true. If one can have experiences that make a judgment

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<sup>144</sup> Translation amended.

more or less probable, then one is capable of achieving objective grounds for the judgment. According to Chignell, there is a subclass of beliefs, called ‘theoretical beliefs,’ that have a special kind of subjective grounds. Such a theoretical belief is hypothetically necessary for the achievement of some theoretical end (Chignell 2007: 349). For example, the transcendental principles of systematicity (those that hold that nature is constituted in such a way that a system of natural concepts is possible) cannot be known, for they assert something beyond the possibility of experience. They nevertheless have *theoretical merit*, for they are necessary for the achievement of a theoretical system of the understanding’s cognitions. Insofar as one’s scientific ends include the systematization of nature, one must assent to these principles. Analogously, the principle that phlogiston is the bearer of inflammability makes possible chemical laws of combustion and calcinability, and so belief in this principle is thereby warranted for the achievement of the ends of chemistry. As phlogiston is not a possible object of experience, one cannot have sufficient objective grounds for its existence; that is, *no* experience will make the existence of phlogiston more or less probable. Thus, although we cannot have *knowledge* of phlogiston, the chemical objectives of explanation and real grounding require its postulation.

This reading also makes sense of the *prima facie* opaque counterfactual claim made by Kant in KpV (above, section 2). There Kant reports that chemical laws “would be cognized *a priori* from objective grounds if our insight went deeper.” He means to consider the counterfactual scenario in which we would have *a priori* cognition, and not mere belief, of the chemical elements. In this case, the chemical laws—as consequences of the natures of the elements—would be cognizable *a priori*, making chemistry into a proper science analogous to physics. However, in our world the chemical elements cannot be cognized *a priori*, meaning that

the chemical laws cannot be cognized *a priori*. My interpretation finds independent support from coherently clarifying this passage otherwise remote from Kant's natural philosophic concerns.

#### 4.2. Explanation Via Unification

The second difficulty facing my view regards the apparent explanatory vacuity of ideas. Phlogiston, one may claim, cannot genuinely *explain* calcination, for it is a mere stand-in for that very property (of being calcinable). That is, phlogiston is analogous to Molière's dormitive virtue: each equates its *explanandum* with its *explanans*.

In response, one ought to observe that phlogiston is more than a mere surrogate for calcinability. Stahl's experiment reveals that phlogiston is the real ground for *both* calcination *and* combustion phenomena, thus uncovering a deep connection between these processes that would not be captured by mere postulation of occult powers that correspond one-to-one with observed properties. For Kant, scientific achievements or explanations are primarily unifications of phenomena: the primary and characteristic end of science is the maximal unification of nature (Butts 1994: 276).<sup>145</sup>

Furthermore, Kant's characterization of chemical elements as surrogates for particular causal powers and of the methodology of chemistry as aiming at unification reflects the chemical practice of his time. Carrier (2001: 215–9) argues that this approach to chemistry, what he calls the chemistry of principles and what I call the power conception of the elements, is the background to Kant's chemical thought.<sup>146</sup> Chemists adhering to the power conception of elements, like Stahl, postulate a small class of principles or elements that are the bearers of

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<sup>145</sup> Morrison (1989; 2008) also emphasizes the importance of unification for Kant's conception of science.

<sup>146</sup> For more on this approach to chemistry, see Thackray (1970: 165–76) and Schofield (1970: 95ff.).

observable, chemical properties, such as inflammability, acidity, or volatility.<sup>147</sup> As Carrier notes, a one-to-one correspondence between principles and chemical properties yields a useless theory, whose principles are indeed no better than dormitive virtues. The objective of this approach to chemistry is the reduction of all chemical properties and phenomena to a small class of elements. For instance, as I explained above, Kant begins with the postulation of five elements; his list is characteristic of chemical practice of the time. Additionally, his division between the active elements (salt and phlogiston) and their respective vehicles (water and fire/air), mirrors similar divisions in the work of Stahl and Boerhaave.<sup>148</sup> Indeed, Kant's regulative ideal of chemistry—the unification and explanation of all chemical powers and reaction under these elements—matches the methodology and goal of the chemistry of principles. It is therefore no wonder that Stahl is lauded by Kant in this context. Stahl's phlogistic chemistry is an exemplar of this approach to the science: he unifies processes such as combustion, calcination, and fermentation with his phlogistic principle. So, although Kant's power conception of chemical practice may seem foreign to the present-day reader, it well reflects the science of Kant's day.<sup>149</sup>

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<sup>147</sup> Ernst Cassirer's description of the elements of this approach to chemistry is apt: they are "hypostatizations of the especially striking sensuous qualities" (1923: 205).

<sup>148</sup> These thinkers distinguished between chemical elements and chemical instruments. Instruments make reactions and the motion of the elements possible. So, for instance, fire was a common instrument for the activity of phlogiston. Kant identified the same instruments as Stahl, namely fire and water (Chang 2002: 38). For more on Stahl's use of instruments, see Carrier (2001: 218). Boerhaave thought that the chemist studies only instruments (fire, air, water, earth, and menstrua): see Powers (2012: 64).

<sup>149</sup> Another point about the background to Kant's chemical thought: as I explained in chapter 1 Kant defines chemistry as the "science of the inner forces of matter" (OP, 21.453); see also (DP, 29.116f.; MAN, 4.530). In DP (29.167), Kant claims that alkalis "attract" acids and likens their action to that of magnets. I take this to be a nod to the Newtonian chemical tradition of postulating short-range attractive and repulsive forces to account for chemical phenomena. Kant hence synthesizes the Stahlian and Newtonian traditions by making each of his elements surrogates for particular attractive or repulsive forces.

### 4.3. Two Kinds of Necessity

Finally, it appears that, in necessitating empirical laws, my account collapses the distinction between *a priori* and empirical laws of natural science. Underlying this challenge is an apparent deep inconsistency in Kant's conception of laws. While Kant claims that chemistry has genuine (and hence necessary) laws, he also claims that its laws are *empirical*, and "carry with them no consciousness of their *necessity* (they are not apodictically certain)" (MAN, 4.468).

Commentators have advanced a variety of resolutions of the apparent contradiction between these claims. First note that there clearly must be a sense in which chemical laws are contingent: a view that entails that such laws are *a priori* in the sense of being necessary for the possibility of experience must be rejected out-of-hand. Friedman argues that the laws of chemistry (and of any improper science) are contingent through-and-through: They are mere empirical regularities and carry nothing of necessity with them. Although this interpretation resolves the seeming contradiction regarding chemical laws, it does so at the price of collapsing the rational/proper science distinction (as I argued above). According to Buchdahl (1966, 1971), by contrast, there must be *two kinds* of necessity at work in Kant's philosophy of science.<sup>150</sup> Buchdahl argues that key Kantian concepts, like that of necessity, are actualized at the level of the understanding and at the level of reason. From the perspective of the understanding, a representation is necessary if it is a condition for the possibility of experience. From the perspective of reason, a representation is necessary if it is a component of an ideal systematization of cognitions of the understanding.

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<sup>150</sup> In his earlier work, Friedman (1992a: 174) endorses multiple kinds of necessity, as well (though his kinds differ from Buchdahl's). The laws of general metaphysics (the pure principles of the understanding) are *absolutely* necessary. The laws of special metaphysics of body, especially the law of universal gravitation, are *derivatively* necessary in virtue of being grounded in the pure principles of the understanding (via the propositions of MAN). However, the laws of physics are also contingent insofar as they depend upon empirical nature.



I would like to appropriate and supplement this basic division. Buchdahl argues that according to the understanding's standards the laws of chemistry are contingent, for they are not conditions of the possibility of experience. To supplement Buchdahl's view, I contend that there is an further sense in which these laws are contingent. In the context of epistemic justification, the warrant (objective grounds) for the laws of chemistry are always experiential. Since the ideational first principles of the science are theoretical beliefs regarding ideas of pure reason beyond the possibility of experience, they can neither be known nor serve as the epistemic (objective) ground for the judgments of chemistry. Therefore, the laws of chemistry are contingent in the sense that their epistemic warrants are *empirical* or *experimental*: they are thus epistemically contingent. However, from the perspective of reason, these laws follow necessarily from the nature of the elements. Nevertheless, chemical laws are not apodictically certain, like the laws of a *proper* science. The laws of a proper science, like physics, are apodictically certain because they are derived from *a priori* laws of general metaphysics and mathematical construction (MAN, 4.470).<sup>151</sup> So the laws of chemistry may "carry with them an expression of necessity," insofar as they are derived from ideational first principles, without being apodictically certain or necessary like the laws of a proper science.

My interpretation can be understood as a supplement to Buchdahl's somewhat sketchy notion of rational necessity. Where he takes the necessity of empirical laws to follow in some vague sense from the *a priori* idea of systematicity, I have tried to show that there are more proximate sources of necessity in empirical sciences achieved through the hypothetical use of

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<sup>151</sup> A detailed consideration of the necessity of physical laws is beyond the scope of this chapter. What is important for our topic is that the laws of physics (proper, rational science) and chemistry (improper, rational science) are necessary in different senses. Physics' laws are necessary in virtue of being grounded in the *a priori* principles of the understanding, while the laws of chemistry are grounded by *a priori* ideational principles of reason. Note that my account thus breaks from Buchdahl's, for he believes the laws of all sciences to be necessary in the same way. My understanding of physics' status allows for less 'looseness of fit.'

reason (like the chemical elements). In another sense, my views may be characterized as a supplementation of Friedman's views. Where Friedman accounts for the possibility of proper science by grounding the necessity of its laws in the pure principles of the understanding, I account for the possibility of rational science by grounding the necessity of its laws in the ideas of reason. Similarly, my interpretation is complementary to Vanzo's (2012: 85–9). Kant's experimental, inductive method, on its own, cannot produce genuine empirical laws. Some *a priori* grounds for necessity are required. I, unlike Vanzo, recognize the possibility of ideas of reason constituting such grounds.

## 5. On Psychology and Experimentation

As I have noted, Kant also calls chemistry an experimental doctrine. I end this chapter by explaining the importance of experimentation in distinguishing chemistry from other sciences. After explaining that chemistry is a merely improper science in the preface to MAN, Kant considers the scientific status of empirical psychology.

[T]he empirical doctrine of the soul can also never approach chemistry even as a systematic art of analysis or experimental doctrine, for in it the manifold of inner observation can be separated only by mere division in thought, and cannot then be held separate and recombined at will (but still less does another thinking subject suffer himself to be experimented upon to suit our purpose), and even observation by itself already changes and displaces the state of the observed subject. Therefore the empirical doctrine of the soul can never become anything more than an historical doctrine of nature, and, as such, a natural doctrine of inner sense which is as systematic as possible, that is, a natural description of the soul, but never a science of the soul, nor even, indeed, an experimental psychological doctrine. (MAN, 4.471)

In this passage, Kant denies psychology the status of a rational science; this denial however, is *prima facie* troubling for my account of chemistry's propriety, for Kant discusses psychological ideas of reason in the Appendix to the Transcendental Dialectic of KrV.

Among the different kinds of unity according to concepts of the understanding belongs the causality of a substance, which is called “power.” At first glance the various appearances of one and the same substance show such diversity that one must assume almost as many powers as there are effects as in the human mind there are sensation, consciousness, imagination, memory, wit, the power to distinguish, pleasure, desire, etc. Initially a logical maxim bids us to reduce this apparent variety as far as possible by discovering hidden identity through comparison and seeing if imagination combined with consciousness may not be memory, wit, the power to distinguish or perhaps even understanding and reason. The idea of a **fundamental power**—though logic does not at all ascertain whether there is such a thing—is at least the problem set by a systematic representation of the manifoldness of powers. (KrV, A648f./B677f.)

In this passage, Kant suggests that reason postulates its own idea, that of a fundamental power, as the basis for the causal powers of the mind that we experience. But then, the troublesome line of thought continues, there would be an *a priori*, ideal, causal ground for the activities of the mind: namely, this idea of a fundamental power. This means that the judgments of psychology—the doctrine of the mind—would be necessary in virtue of this ground in the same way that the judgments of chemistry are necessary in virtue of the elements, making psychology a rational science. This conclusion, however, conflicts with Kant’s explicit denial of psychology’s rationality in the above passage of MAN.

I contend that my interpretation of scientific rationality deals especially well with this difficulty and makes clear why experimentation is essential for explanation. Note that in the above passage from KrV Kant speaks of the idea of a fundamental power as the result of a *logical* maxim that bids us to unify our cognitions—the principle of homogeneity. That is, the idea of a fundamental power is merely the *logical* ground for the other mental powers. After its postulation, the real unification of powers of the mind under the idea of a fundamental power remains a *problem* for reason. For the unification of the mind’s powers to be more than merely logical—that is, to *really* unify the powers of the mind—one must discover the “hidden identity” amongst the powers. In this passage, Kant is claiming that we must have some experience that

justifies this real unification the powers of the mind under their causal basis. This case is analogous to the case from chemistry of unifying inflammability phenomena. Before Stahl's experiment, one may have proposed that calcination and combustion phenomena are unified by some unknown idea, but this would be a mere logical unification, based on their shared marks. With Stahl's experiment, we discover that the power that *really* grounds calcination also *really* grounds combustion. In order to unify the powers of the mind under their real ground, we require an analogous experience that reveals this unification.

And the possibility of such an experience is precisely what Kant rules out in the passage from MAN. Since we cannot separate and recombine the powers of the mind at will, we cannot determine their hidden identities. As I explained above, the epistemic warrant for the judgments of a rational science ultimately comes from below: that is, from experiments contrived by reason. Without experimentation, the unification of cognitions in a science remains merely hypothetical: that is, a unifying principle postulated by reason remains a *problem* without verification (without checking particulars to see if they flow from the rule). For this reason, in lieu of experimentation, psychology is further removed from the rank of proper science than chemistry. Furthermore, consideration of this case makes sense of why Kant calls either a rational science or an experimental doctrine. Since we can take our principles to experience in chemistry, we can confirm or disconfirm them, meaning that, we can achieve epistemic warrant for the causal laws of chemistry. Experimentation and scientific rationality go hand in hand.

## CHAPTER 3

### Chemistry in Kant's *Opus Postumum*

In MAN, Kant claims that chemistry is improper because, unlike physics, it does not adequately allow for the application of mathematics—a criterion that I titled the ‘mathematization condition’ in chapter 1. Nevertheless, I argued in chapter 2 that chemistry is rational because, unlike mere aggregates of cognitions, it has genuine causal laws (MAN, 4.468), and that Kant means to confer this status to the phlogistic chemistry of Stahl. This phlogistic conception of chemistry also appears in Kant’s 1785 physics lectures and throughout his *Reflexionen* on chemistry in the 1780s.

By the 1790s, Kant’s views on chemistry shift. In MS, he claims that the one chemistry is that of Lavoisier (6.206), while Archimedes, Newton, and Lavoisier are Kant’s exemplars of scientific genius in Anth (7.327).<sup>152</sup> Guyer and Wood also note that Kant attended a replication of Lavoisier’s experiments in 1796 (Kant 1998: 715n.). In fact, in OP, the work in which Kant gives his most sustained consideration of chemistry, he appears to espouse a broadly Lavoisierian conception of chemistry. The elements characteristic of phlogistic chemistry are replaced with Lavoisier’s oxygen, hydrogen, nitrogen, and so on (OP, 21.605; 22.429, 462, 508f.).<sup>153</sup> The caloric, to which Lavoisier appeals to explain a variety of phenomena, receives considerable attention in Kant’s OP. Kant, like Lavoisier, takes caloric (or aether)<sup>154</sup> to explain thermal behavior (OP, 21.378) and to play a key role for the explanation of states of aggregation

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<sup>152</sup> In Refl 66 (14.489), from the 1780s, Kant explains the Lavoisierian understanding of combustion.

<sup>153</sup> In Refl 71 (14.502), from 1793–4, Kant presents Lavoisier’s elements, citing Girtanner (1792). For more on Girtanner, see the prologue.

<sup>154</sup> Following Kant, the terms “aether” and “caloric” are used interchangeably.

(OP, 22.213). Moreover, it is the “basis for the unified whole of all moving forces of matter (the hypostatized space itself, as it were, in which everything moves); the principle of the possibility of the unity of the whole of possible experience” (OP, 21.224). The section of OP that has received the most attention from commentators is the so-called aether deduction, in which Kant argues that the aether—this basis for moving forces—is a necessary precondition for the possibility of experience.<sup>155</sup>

These changes in Kant’s conceptualization of chemistry raise the question of whether Kant continues to think that chemistry is an improper, though rational, science after his assimilation of Lavoisier’s chemical revolution. In this chapter, I answer this question in the affirmative and highlight the continuity in Kant’s views on chemistry between MAN and OP. In section 1, I describe and ultimately reject a seemingly natural interpretation of Kant’s views on chemistry, according to which he reconsiders chemistry’s impropriety after his exposure to Lavoisier’s theory. In section 2, I argue *contra* Tuschling (1971) that in OP Kant holds fast to the mathematization condition. In section 3, I explain that, because Kant retains his views on the chemical elements, chemistry remains a rational science in OP. Additionally, in this section, I argue that the prominent additions to Kant’s account of chemistry in OP—to wit, the aether proof and the *a priori* deduction of the elements—do not make the science a proper one.

But before I continue, I ought to explain my approach to OP, because different drafts of the text contain markedly different arguments and endorse varying theses. In this paper, I defend an interpretation of Kant’s views on chemistry especially as expressed in the “Übergang 1–14” drafts—which appear in the II<sup>nd</sup> and V<sup>th</sup> fascicles of OP and have been dated to May–August

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<sup>155</sup> For varying reconstructions and interpretations of the aether deduction, see Edwards (2000: 145–92), Förster (2000: 82–101), Friedman (1992b: 290–341), and Hall (2006).

1799—and in the “A–Z” drafts—which appear in the X<sup>th</sup> and XI<sup>th</sup> fascicles and are dated to August 1799–April 1800.

I examine the drafts of OP written during this period for a few reasons. First, I claim that Kant’s views on chemistry and its elements undergo no major changes during these drafts. Throughout these drafts of OP, Kant believes that the aether is a non-hypothetical material, whose existence can be derived *a priori* and that the moving forces of matter (or the elements) may be enumerated *a priori*. When I cite material from OP written prior to these fascicles (especially material from the VIII<sup>th</sup> and IX<sup>th</sup> fascicles), I contend that Kant continued to endorse cited claims in the time period under examination. For instance, below I utilize claims from Kant’s *Oktaventwurf*—earliest writings properly belonging to the transition project, written in 1796–7—but only those that are consistent with the X<sup>th</sup> and XI<sup>th</sup> fascicles, such as those concerning the role of the aether in grounding empirical natural behavior (a topic that undergoes little change throughout OP). By contrast, I do not, in this paper, utilize Kant’s claim from the *Oktaventwurf* that the aether is a hypothetical material (OP, 21.378),<sup>156</sup> as he rejects this claim during the time period under investigation. Second, these drafts of OP give the strongest possible case for chemistry’s propriety. A proper science, as I have noted, has an *a priori* core. The X<sup>th</sup> and XI<sup>th</sup> fascicles contain the most *a priori* content that bears on chemistry. Earlier drafts of OP, wherein the aether is merely hypothetical and Kant does not endorse an *a priori* enumeration of the elements, thereby offer a weaker case for chemistry’s propriety. Similarly, Kant’s apparent pessimism with respect to the aether deduction after writing the XI<sup>th</sup> fascicle means that later drafts could only present a weaker argument for chemistry’s being a proper science. So in this

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<sup>156</sup> See Förster (2000: 92).

paper, I argue against the strongest possible case for chemistry's propriety. Other variations in OP, such as the different versions of the enumeration of the elements, do not affect my argument.

### 1. Overestimating the Balance

Henri Dussort (1956) presents an intuitive and plausible interpretation regarding the influence of Lavoisier's chemistry on Kant, one that resonates both with a similarly plausible interpretation of Kant's conception of the application of mathematics and with the customary history of the chemical revolution. Ultimately, I reject Dussort's interpretation for depending upon an implausibly weak interpretation of the mathematization condition and for resting on a simplified, whiggish history of chemistry.<sup>157</sup>

Dussort contends that, when Kant denies chemistry the status of proper science, he means to refer specifically to the phlogistic chemistry of Georg Stahl. With his shift to Lavoisier's chemistry, however, Dussort contends that Kant reevaluates the status of chemistry, for Lavoisier "systematized the use of the balance, in this way making possible the application of mathematics [in chemistry], which is required, at least according to Kant, by [proper] science" (Dussort 1956: 395). So, according to Dussort, the use of the balance, which is purportedly missing from Stahlian chemistry, makes possible the application of mathematics to chemistry and hence makes the science a proper one.<sup>158</sup>

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<sup>157</sup> A whig history of science depicts science as inevitably progressing towards present practices and theories. They commonly depict scientists whose work more closely resembles present science (however superficially) as superior to their detractors and forerunners. For the whig historian, the history of science is a linear progression of great scientists, whose contributions ultimately produced contemporary science. Lavoisier is a common hero of such histories.

<sup>158</sup> Friedman (1992b: 264–90) concurs that Kant was more optimistic about *a priori* foundations for the science of chemistry in OP, although he offers a more informed and nuanced diagnosis of this optimism. I argue against Friedman's view in detail in section 3.



As Dussort suggests, his account dovetails with the received history of the chemical revolution. Though this rendition of the history has long since become *passé* amongst historians,<sup>159</sup> it lives on in the popular imagination. Chemical textbooks, especially, propagate this whiggish depiction of the Lavoisier's chemical revolution. According to this view, prior to Lavoisier, chemistry was primarily concerned with qualitative properties of substances and their modifications in chemical reactions. Lavoisier's emphasis on meticulous measurements of the weights of reagents and products, however, allowed him to discover the central defect with Stahlian chemistry: weight-gain during calcination. The phlogistic chemists believed that phlogiston is released from a burning substance, yet during calcination a metal *gains* weight. It is *prima facie* inconsistent to claim that a metal *gains* weight whilst it is *losing* phlogiston during calcination. According to the received history of the chemical revolution, only through ignorance of this fact or of quantitative measurements generally could the phlogistic theory be upheld. As a classic history of chemistry puts it, "The setting up and the subsequent development of the phlogistic doctrines were only possible because of the utter neglect of quantitative relations" (von Meyer 1898: 99). So Lavoisier's use of the balance and quantitative measurements calls attention to the problem of weight gain during calcination and the phlogistic theory is overthrown. According to Dussort, Kant was similarly moved by Lavoisier's use of quantitative measurements and reconsiders chemistry's status.

There are three sorts of problems with Dussort's account. First, it misinterprets Kant's conception of proper science, depending upon a far-too-weak interpretation of the mathematization condition. As I argued in chapter 1, Kant thinks of the mathematization condition as requiring *a priori* principles for the *mathematical construction* of the concepts of the

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<sup>159</sup> But it can be found in older histories, such as von Meyer (1898).

science. This use of mathematics is then supposed to make possible further *a priori* cognitions in the science (MAN, 4.470). The fact that quantitative techniques are employed in a science is however utterly insufficient for the derivation of such *a priori* principles for construction: Kant contends that only metaphysics can ground such mathematical principles in physics. The use of the balance or measurements of specific weight brings us no closer to *a priori* metaphysical validation for the use of mathematics in chemistry.

Second, Dussort's account is based on a whiggish, inaccurate history. Quantitative measurements are common in pre-Lavoisierian chemistry, as noted by historian Henry Guerlac.

It has long been a cliché of histories of chemistry that Lavoisier's chief contribution was to usher in the age of quantitative chemistry, to enunciate for the first time the principle of the Conservation of Mass in chemical reactions, and to inaugurate the use of the balance. To say the least, this is a gross oversimplification. [...T]he testimony of the balance was increasingly invoked by chemists, especially by the British school—the school of Boyle, Newton, Mayow, and Hales—which sought to develop a “statical,” that is to say a quantitative, chemistry akin to physics. By the mid-eighteenth century it was piously hoped that every chemical operation would be performed “in an exact or geometrical manner,” with the use of accurate balances and weights. (Guerlac, 1961, xvi)

Not only were chemists using measurements in the mid-18<sup>th</sup> century, but further Kant knew of these practices by the Critical period. As I have previously argued in the prologue and chapter 1, Kant discusses figures of the British, statical school in pre-Critical works from the 1750s and was exposed to a variety of information regarding measurements from sources such as Karsten, Wallerius, and Erxleben by the mid-1780s. In fact, while Lavoisier, himself, emphasized measurements of specific weight, such measurements were common in chemistry before him, and Kant knew of this to be the case. Were the use of quantitative measurements the standard of

scientific propriety, Kant would judge pre-Lavoisierian chemistry to be proper in the Critical period.<sup>160</sup>

Third, textual evidence undermines the contention that the balance (or quantitative measurement generally) serves a dramatically new function in Kant's theory of chemistry in OP. Were the balance at the center of a modified conception of chemistry, it could be expected that Kant would offer a new account of its functioning or, at least, highlight its importance for chemistry. Yet, Kant's account of the balance in OP matches that given in MAN, belying a newfound role for the device. Many drafts of OP follow the Kant's architectonic framework of the categories, whereby he enumerates the quantity, quality, relation, and modality of matter.<sup>161</sup> Regularly, consideration of the balance arises when Kant considers the quantity of matter (OP, 22.207f., 210). In such passages, Kant claims that "The quantity of matter can thus be measured neither arithmetically, by the number or corpuscles, nor geometrically, by volume, but only mechanically, by the quantity of the moving force which a volume of matter exercises in one direction and at one velocity of motion upon a movable object" (OP, 22.207). These claims echo those Kant makes regarding the quantity of matter in Proposition 1 of MAN's Mechanics, along with its notes and remarks. There he writes that "The quantity of the movable in space is the quantity of matter; but this quantity of matter (the aggregate of the movable) *manifests itself* in experience only by the quantity of motion at equal speed (for example, by equilibrium)" (MAN, 4.540). In both texts, Kant is concerned to rule out merely mathematical determinations of the

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<sup>160</sup> Furthermore, von Meyer's claim that the phlogistonists were ignorant of quantitative measurement is unfair. Phlogistic chemists had a variety of explanations of weight-gain during calcination (White 1932: 46; Partington and McKie 1937). Though some explanations may strike us as implausible—e.g., that phlogiston is lighter than air—that such proposals existed demonstrates that the received history is defective.

<sup>161</sup> This approach is especially characteristic of early drafts of OP, especially A–C,  $\alpha$ – $\epsilon$ , a–c, and No. 1–No. 3 $\eta$ .

quantity of matter in favor of his mechanical account,<sup>162</sup> according to which we can determine the quantity of matter through equal forces on a balance.<sup>163</sup> In OP, the balance takes on no further fundamental role with respect to the propositions of physics or chemistry.

The only apparent difference between MAN and OP regarding the balance is that in the latter Kant is more concerned with the presuppositions behind its functioning. The activity of the balance presupposes its rigidity: if its arms were not rigid, it could not serve for the measurement of weight (22.138). But rigidity, according to Kant, is only possible in virtue of the caloric.

Thus the ponderability of matter is not a property knowable *a priori* according to the mere concept of the quantity of matter; it is, rather, physically conditioned and requires the presupposition of an *internally* moving matter which results in the immobility of the parts in contact with one another, by itself being mobile inside this matter. We know of no other matter to which we have cause to attribute such a property, except caloric. Thus, even ponderability (represented subjectively as the experiment of weighing) will require the assumption of a matter which is not ponderable (*imponderabilis*); for, otherwise, the condition for ponderability would be extended to infinity, and thus lack a foundation. (OP, 22.138f.)<sup>164</sup>

The fact that Kant believes the ponderability of matter to presuppose the existence of the caloric does not show that Kant reevaluates chemistry's propriety based on Lavoisier's use of the balance. Furthermore, the passages in which Kant explicitly discusses the balance are separate from those on chemistry. Hence, Kant gives the balance greater consideration in OP, but he fails to develop any views on its use in the chemical context. Dussort's account of Kant's views on

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<sup>162</sup> In particular, Kant means to deny Descartes' geometrical conception of the quantity of matter—according to which the quantity of matter is determined by volume—as well as Lambert's and Laplace's corpuscular conceptions of matter—according to which quantity of matter is determined arithmetically by the number of corpuscles.

<sup>163</sup> My views on Kant's estimation of quantity of matter are informed by Friedman's insightful examination of Kant's mechanics: see, especially Friedman (2013: 293–311). In this section, Friedman explains that Kant's general, mechanical method of estimating quantity of matter is meant to include measurements by impact and via the balance (though Kant prefers the latter).

<sup>164</sup> Kant makes a similar claim at OP (21.315).

chemistry is, indeed, *prima facie* plausible and dovetails with the received history of the scientific revolution, but we have many reasons to be skeptical.

## 2. Mathematics Remains Essential to Proper Science

I argued that Dussort's account fails because proper natural science requires principles for the mathematical construction of its objects and not mere quantitative measurements, but Tuschling challenges the very idea that Kant retained this notion of scientific propriety in OP. In this work, Kant aims to present a *transition* from the metaphysics to physics: "*Physica generalis* thus contains the necessity of the transition from the metaphysical foundations of natural science to physics, in virtue of the relationship which is to be found between *a priori* rules and the knowledge of their application to empirically given objects" (21.407f.). Tuschling (1971: 90–122) argues that the transition is meant to *replace* MAN's account of natural science. For our purposes here, Tuschling's claim that in OP Kant denies that mathematical construction is necessary in a proper science is of particular interest. If it is the case that Kant no longer thinks mathematical construction to be essential to the propriety of a science, then chemistry may become a proper science *independent* of any newfound mathematization. Additionally, this development would show my question regarding chemistry's propriety to be anachronistic after 1786. *Contra* Tuschling, I concur with Friedman (1992b: 222–42) that Kant did not reject the mathematization condition in OP: rather, the passages that appear to repudiate the mathematization condition highlighted by Tuschling ought better be understood as echoes of

Kant's rejection of mechanical philosophy in MAN.<sup>165</sup> Thus, mathematization remains the standard of proper science for Kant, and chemistry remains improper.

Tuschling (1971: 91) argues that a number of passages in OP fall under the category of *Mathematicpolemik*. In such passages, Kant denies that mathematical foundations play a role in natural philosophy.

In the part of the philosophical science of nature (*philosophia naturalis*) entitled the metaphysical foundations thereof, there already lies a tendency toward *physics* as the goal to which it is directed—namely, to expound the empirical doctrine of material science in a system. What are called the *mathematical* foundations of science of nature (*philosophiae naturalis principia mathematica*), as expressed by Newton in his immortal work, are (as the expression itself indicates) no part of the *philosophy of nature*. They are only an instrument (albeit a most necessary one) for the calculation of the magnitude of motions and moving forces (which must be given by observation of nature) and for the determination of their laws for physics (so that the quality of the motions and moving forces can be specified in regard to the central forces of bodies in circular motion, as well as the motion of light, sound and tone, according to their direction and degree). Consequently, this doctrine properly forms no part of the philosophical study of nature. (OP, 21.481f.)

In this passage and a number of others cited by Tuschling, Kant appears to backtrack on the necessity of mathematics for proper natural science. Such passages stand in stark contrast to the approach of MAN: “in any special doctrine of nature there can be only as much *proper* science as there is *mathematics* therein” (4.470). So, according to Tuschling, whereas Kant characterizes mathematics as necessary for the possibility of proper science in MAN, he contends that it is a mere instrument in OP.

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<sup>165</sup> To be clear: I do not endorse all aspects of Friedman's interpretation of Kant's philosophy of science in the Critical period and OP. In particular, there are significant difficulties facing his account of Kant's derivation of the Law of Universal Gravitation (Friedman 1992b: 165–210), and I do not think that developments in late 18<sup>th</sup> century chemistry were the primary motivation behind Kant's transition project (Friedman 1992b: 264–90). Although my thoughts on the Law of Universal Gravitation are beyond the scope of this dissertation, I explain below that Kant's conception of chemistry in OP conflicts with, for instance, Lavoisier's chemistry, putting pressure on Friedman's understanding of the motivations behind OP. Nevertheless on the particular issue of Kant's views on the application of mathematics in natural science, Friedman presents the most sensitive, charitable, and plausible interpretation, which I endorse and support with new arguments, below.

One might think that this is a revision to Kant's thought: in OP, mathematics is used at the level of empirical physics—to calculate masses and velocities—but no longer plays its essential role in making possible *a priori* cognition of nature. Similar passages are found throughout OP, commonly in conjunction with Kant's protest to the title of Newton's *Philosophiae Naturalis Principia Mathematica*.

But there is a self-contradiction in the very title of his book: For, just as little as there can be *philosophical principles of mathematics*, can there be *mathematical principles of philosophy* (such as physics is supposed to contain). It should have been called: *Scientiae naturalis principia mathematica*; the [above] principles cannot be subordinated to each other but must be placed side by side. (OP, 22.512)

For Kant, philosophy takes care of itself: Newton's proposed combination of mathematics and philosophy is illegitimate. Tuschling takes such passages such as these to show that Kant came to reject the mathematization condition of proper science in OP. The metaphysical foundations for natural science and the transition therefrom to empirical physics must proceed philosophically.

*Contra* Tuschling, I contend that when Kant rejects mathematical foundations in OP, he is *not* jettisoning the mathematization condition. In section 2.1, I explain and offer new support for Friedman's interpretation, according to which, by rejecting mathematical foundations in OP, Kant actually means to reaffirm his rejection of *mechanical philosophy*—a motif found throughout his philosophical corpus. In 2.2, I respond to objections to this interpretation from Edwards and Westphal. Finally, in 2.3, I present additional evidence for the thesis that Kant held fast to the mathematization condition, resting upon his argument for the condition in MAN.

## 2.1. Mathematical Foundations vs. Philosophical Foundations

In OP, Kant explains that *mathematical* foundations of natural science derive moving forces from motions whereas *philosophical* foundations of natural science derive motions from

forces (22.513, 515f.). Tuschling maintains that Kant's rejection of mathematical foundations involves a redaction of the first dynamical law of MAN: "Matter fills a space, not through its mere *existence*, but through a *particular moving force*" (4.497). The argument for this proposition proceeds as follows. The filling of space is resistance to motion, so a matter moving into a filled space has its motion diminished. The only thing that can diminish the motion of a body is a contrary motion of that selfsame body. So, the filling of space is a cause of a contrary motion in a penetrating body; such a cause is a moving force. Tuschling believes this proof to be a paradigm of mathematical foundations of natural science, beginning with motions and deriving moving forces therefrom, and hence that Kant rejects this proposition by the drafting of OP. As the rest of MAN—the remainder of the Dynamics, the Mechanics, and the Phenomenology—all depend upon the forsaken first proposition of the Dynamics, its rejection means that the valid content of MAN reduces to the Phoronomy. Passages purportedly supporting this claim fall under the category of *Phoronomiekritik* (Tuschling 1971: 90f.).<sup>166</sup> As such, the transition project is undertaken to fill this lacuna in Kant's account of natural science.

Friedman (1992b: 222–42) contends that Tuschling misunderstands Kant's rejection of mathematical foundations. He explains that, according to mathematical foundations of natural science, motions are *causes of* moving forces. This approach to natural science is characteristic of corpuscularism, according to which, observable phenomena are explained by the *motion* of absolutely impenetrable corpuscles. Conversely, according to philosophical foundations of natural science, motions are *caused by* moving forces. According to this approach, matters are essentially sources of fundamental forces of repulsion and attraction, and changes in motion—

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<sup>166</sup> Although I am skeptical of Tuschling's *Phoronomiekritik*, engagement with this doctrine is beyond my current concerns. I only raise his argument regarding the first proposition of the Dynamics to clarify better Tuschling's and Friedman's interpretations of mathematical foundations.



like the diminution of motion into a filled space—are explained by appeal to such forces. On Friedman’s understanding of the distinction between mathematical and philosophical foundations the proof of Proposition 1 of the Dynamics proceeds philosophically for it holds that the repulsive force is the *cause* of the diminution of penetrative motion. Thus, this proposition is not subject to Kant’s rejection of mathematical foundations in OP.

In addition to the arguments Friedman presents on behalf of his thesis, further evidence supports his claim. In his 1792–3 metaphysics lectures, Kant describes mechanical philosophy in a manner that identifies it with mathematical foundations of natural science.<sup>167</sup>

The first [mechanical philosophy] derives all alterations of the world from the figure of its fundamental particles, these it assumes as determined, indivisible-*atomi, corpuscula*, themselves still matter, but inseparable. Descartes gave them certain figures (e.g., hooks in *aqua fortis*). All motion was derived from others, which one already assumed. (V-Met/Dohna, 28.664)

Dynamical philosophy, on the other hand, is conceived of as “powers assigned to motions, as Newton assigned attraction, a power that, without all any motion of itself, at rest, sets all others in motion” (V-Met/Dohna, 28.665).<sup>168</sup> So Kant characterizes mechanical philosophy as taking the motions of corpuscles as fundamental. The motion of the hooked corpuscles of *aqua fortis*, for instance, explains its power to dissolve other substances. Hence, in this passage, Kant describes the two modes of explanation along the same lines that he does mathematical and philosophical foundations in OP. Whereas mechanical philosophy and mathematical foundations of natural science take motions as causally basic, dynamical philosophy and philosophical foundations assume forces as fundamental. Additionally, in MAN, Kant refers to mechanical

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<sup>167</sup> In Refl 61 (14.470), Kant claims that the mechanical mode of explanation has to do only with the communication of motion, not its production.

<sup>168</sup> Warren (2010: 206–12) also cites this passage and thinks of mechanical and dynamical approaches as defending opposite directions of *causal* dependence between forces and motions.

philosophy as “the mathematical-mechanical mode of explanation” (4.524f.) and to its adherents as “mathematicians” (4.498) (see chapter 1). These pieces of evidence support the view that the target of Kant’s polemics against mathematical foundations is *not* his former self, but rather mechanical philosophy.<sup>169</sup> So the passages Tuschling highlights give us no reason to think that Kant revises his views on the mathematization condition in OP.

## 2.2. Rejoinders on Behalf of Tuschling

Edwards (2000: 229–39, 241) and Westphal (1995: 409–15)<sup>170</sup> defend Tuschling’s interpretation of OP and criticize Friedman’s account. Although their objections to Friedman are vast and multifaceted, in the present context, only their views regarding the application of mathematics are pertinent.<sup>171</sup> In this section, I defend Friedman’s interpretation of Kant’s rejection of mathematical foundations in OP.

Edwards includes a long string of incisive footnotes directed against Friedman’s interpretation of MAN, OP, and the relationship between them. One such footnote attacks Friedman’s views on mathematical and philosophical foundations (Edwards 2000: 241). According to Edwards, not all forces in Kant’s MAN are conceived of as causes of motions. That is, Friedman’s understanding of moving forces is suited for the mechanical forces—those that communicate motion between bodies—but not the dynamical forces—the fundamental forces of attraction and repulsion, meaning his interpretation is inadequate. There are a number of

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<sup>169</sup> Moreover, as I demonstrate below (section 2.3), evidence from OP shows that Kant thought it necessary to apply mathematics in natural science.

<sup>170</sup> Westphal’s arguments are repeated in chapter 5 of his (2004).

<sup>171</sup> My account only depends upon Friedman’s understanding of mathematical foundations in OP. Furthermore, I do not endorse all aspects of Friedman’s interpretation of Kant’s views on natural science, as I noted above.

problems with this argument. First, it is inadequately sourced: in this footnote Edwards does not substantiate the claim that the mechanical and dynamical forces of matter are fundamentally different. Second, there is a clear sense in which all forces are, as Friedman describes, causes of motion for Kant. Earlier in the book, Edwards (2000: 52) emphasizes the difference in Kant's terminology for mechanical and dynamical forces. By means of a mechanical force, a matter *communicates* its motion to another, whereas, by means of a dynamical force (i.e., either the fundamental force of attraction or that of repulsion), a matter *imparts* a motion to another (MAN, 4.536). So in the mechanical case, a body impacts another to change its motion, whereas in the dynamical case, a body, even at rest, changes the motion of another by means of the fundamental force of attraction or that of repulsion. But in either case the force is conceived of as the effective power by which the one body changes the motion of the other; that is, regardless of situation, motions are caused by forces for Kant. Third, the first proposition of the Dynamics (described above) demonstrates that Kant thinks of dynamical forces fundamentally as causes of motion. From the diminution of the motion of a matter entering a filled space, Kant infers that there must be a cause—the fundamental repulsive force—in the filled space that causes this change in motion. Hence, from the very beginning of the Dynamics, Kant thinks of dynamical forces as causes of motions.

Westphal also includes, amongst his various criticisms of Friedman, arguments against Friedman's interpretation of mathematical foundations (1995: 412). Westphal claims that two issues doom MAN and its mathematical method: to wit, the problem of the first proposition of the Dynamics and the density-circularity problem. First, in the first proposition of the Dynamics Kant claims that the filling of space—the diminution of the velocity of matter moving into another matter's space—is due to matter's expression of a repulsive force. Westphal finds deep

problems with the proof of this proposition, arguing both that the premises of Kant's argument are insufficient for validly inferring the existence of an inherent *causal* power of matter (1995: 391-5) and that the argument appeals to mechanical considerations, meaning that MAN is circular (1995: 405f.). These arguments hence supplement Tuschling's *Phoronomiekritik*. Second, Westphal defends his version of the density-circularity problem, which is a well-worn issue in the secondary literature (1995: 400ff.). According to MAN, all matters are endowed with the fundamental forces of attraction and repulsion, which constitute the basis for dynamical explanation. Kant claims that these forces explain the possibility of different matters variably filling their spaces. The basic idea is that, since the forces are opposed to each other, the outward repulsion of a matter can be offset by its inward attraction, explaining its filling of a space of a particular volume. As the forces of a matter vary, so too does its density and volume. Westphal charges that there is a damaging circularity in this account, which Kant only recognizes years later.<sup>172</sup> According to Kant, density and volume are functions of the fundamental attractive and repulsive forces, as I just explained. However, Kant means for his attractive force to be identifiable with gravitational force—after all, MAN aims to buttress Newton's theories—which entails that the intensity of the attractive force is a function of mass. But mass is just a function of density and volume. This is the circle: density depends upon the intensity of the attractive force, which, in turn, rests on density.

Westphal takes these problems to be disastrous for MAN and to entail that “Kant's effort to imitate the mathematical method, so far as possible, with his constructive metaphysical method must be rejected” (Westphal 1995: 407). However, it is unclear how these problems bear on the application of mathematics in natural science. On the assumption that, by the writing of

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<sup>172</sup>Kant describes the circularity in a 1792 letter to Beck (Br, 11.376).

OP, Kant recognized both the failure of the first proposition of the dynamics and the circularity in his account of density, he is not thereby committed to the negation of the mathematization condition. That is, even if Westphal is right, this does not entail that the use of mathematics in natural science is unnecessary: the failure of one mathematization of nature does not entail the failure of all. Ultimately, Westphal supports the claim that in OP Kant rejected the use of mathematics by merely citing the same *Mathematikpolemik* passages as Tuschling, without adequately responding to Friedman's compelling reading of these passages. That Friedman's interpretation fits awkwardly with *Phoronomiekritik* and the circularity problem is less compelling than the textual support for the claim that Kant's rejection of mathematical foundations is not directed at his former self, but at the corpuscularists.<sup>173</sup> Indeed, the conflict cuts both ways: on the same grounds one may question these doctrines' role in OP. In the end, Edwards and Westphal's arguments are insufficient to establish definitively that Kant rejects the mathematization condition after MAN.<sup>174</sup>

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<sup>173</sup> Furthermore, Tuschling's doctrines face difficulties, including textual evidence from OP. For instance, Kant maintains that there remain fundamental attractive and repulsive forces that explain the filling of space (OP, 22.205f.), that MAN contains laws of motion according to *a priori* concepts (OP, 21.524), and that MAN contains *a priori* laws regarding matter (OP, 22.189).

<sup>174</sup> Westphal presents an additional argument against Friedman's understanding of mathematical foundations: to wit, it "does not explain why Kant modeled metaphysics on mathematics in the MAN (1786), and why in 1798 he rejected the mathematical model" (1995: 412). If, on the one hand, by "the mathematical model," Westphal means to refer to the mathematization condition, his objection clearly begs the question, for, assuming Friedman's interpretation, Kant *does not* reject the mathematization condition in 1798. If, on the other hand, by "mathematical model," Westphal means to refer to the compositional style of MAN, his objection carries no weight. There does not appear to be a deep difference in the structure of MAN and OP: many drafts of OP follow the architectonic of the categories, as does MAN. Furthermore, it is questionable that among the responsibilities of a viable interpretation of mathematical foundations is its explanation of the structure of OP.

### 2.3. The Mathematization Condition in MAN and OP

Furthermore, beyond the above arguments, which primarily rest on textual evidence, there are deep conceptual reasons that Kant could not have modified his views on the application of mathematics in natural science. In sections 2.3 and 3, I argue that it is implausible that Kant rejected the scientific use of mathematics on the basis of a detailed examination of his argument for the essentiality of mathematics to natural science. In the preface to MAN, Kant argues from the condition that a proper science must have *a priori* laws to its requiring the application of mathematics.

I assert, however, that in any special doctrine of nature there can be only as much *proper* science as there is *mathematics* therein. For, according to the preceding, proper science, and above all proper natural science, requires a pure part lying at the basis of the empirical part, and resting on a priori cognition of natural things. Now to cognize something a priori means to cognize it from its mere possibility. But the possibility of determinate natural things cannot be cognized from their mere concepts; for from these the possibility of the thought (that it does not contradict itself) can certainly be cognized, but not the possibility of the object, as a natural thing that can be given outside the thought (as existing). Hence, in order to cognize the possibility of determinate natural things, and thus to cognize them a priori, it is still required that the *intuition* corresponding to the concept be given a priori, that is, that the concept be constructed. Now rational cognition through construction of concepts is mathematical. Hence, although a pure philosophy of nature in general, that is, that which investigates only what constitutes the concept of a nature in general, may indeed be possible even without mathematics, a pure doctrine of nature concerning *determinate* natural things (doctrine of body or doctrine of soul) is only possible by means of mathematics. And, since in any doctrine of nature there is only as much proper science as there is a priori knowledge therein, a doctrine of nature will contain only as much proper science as there is mathematics capable of application there. (MAN, 4.470)

My reading of this argument is as follows:

- (i) A special doctrine of nature concerns itself with determinate objects, of which an empirical concept is given.
- (ii) Proper science, as a special doctrine, yields proper knowledge regarding determinate objects.

- (iii) Proper knowledge requires *a priori* cognition.
- (iv) To cognize something *a priori* is to cognize it from its possibility.
- (v) To cognize an object from its possibility requires that a corresponding intuition be given *a priori*.
- (vi) Only mathematical construction provides *a priori* intuitions corresponding to concepts.
- (vii) Therefore, a special doctrine of nature is only properly scientific insofar as it utilizes mathematical construction.

If Kant rejects the mathematization condition in OP, then he must find fault in this argument, which concludes that mathematical construction is essential to proper science. As it is valid, if Tuschling is correct, then Kant must deny one of the premises. Many of the claims of this argument are more-or-less definitional, others are essential to the Critical project. There are few modifications Kant could plausibly have made. First, he might have simply rejected the possibility of *a priori* laws of determinate objects, thus rejecting the very possibility of a proper natural science. Yet throughout OP Kant repeatedly claims that there is still an *a priori* (metaphysical) core to natural science, so the doctrine of body must be proper: “The doctrine of the laws of the moving forces of matter, insofar as they are known *a priori*, is called metaphysics; insofar as they can only be derived from experience, physics” (21.310).<sup>175</sup>

Second, Kant may have rejected (v) or (vi), holding that mathematical construction is *not* required for *a priori* knowledge of natural things. However, throughout OP, Kant is clear that he

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<sup>175</sup> Throughout OP, Kant repeats this claim and also specifies that the *a priori* laws of natural science belong to its metaphysical foundations (21.164, 408; 22.187, 265). Note that Kant also claims that the transition science has *a priori* principles. In section 3, I contend that these principles are of a different sort—they are principles anticipating the form of the system of physics—and hence do not require the application of mathematics.

retains a substantive use for mathematics in natural science. For example, he explains that, because the use of mathematics in natural science requires metaphysical validation, metaphysical foundations are required in an account of natural science (OP, 21.527), echoing claims regarding the relationship between the application of mathematics and metaphysics made in MAN (4.467n., 472). After the passage cited above, in which Kant takes issue with the title of Newton's *magnum opus*, he continues as follows.

*Physics* is an empirical system of the moving forces of nature and a problematic whole thereof. The transition from the metaphysical foundations to the science of nature in general, represented *a priori*, according to the formal principles of mathematics and philosophy, is a transition in which mathematics supplies only the application of concepts to intuitions *a priori*, by anticipations, etc., not fragmentarily, as a mere aggregate, but systematically, according to one principle. Without these premises there can be no science of nature. (OP, 22.512f.)<sup>176</sup>

Though mathematics on its own cannot yield scientific knowledge, it allows the natural scientist to achieve *a priori* laws for the moving forces of matter: motions and forces remain subject to mathematical principles. Throughout OP, Kant claims that mathematics is necessary for the transition from the metaphysical foundations of natural science to physics, and he ultimately contends that mathematics and philosophy must be *united* for the science of nature (OP, 22.491).<sup>177</sup>

Thus, *pace* Tuschling, Edwards, and Westphal, in OP Kant continues to hold that the application of mathematics is essential to proper science. Proponents of Tuschling's

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<sup>176</sup> Elsewhere in OP (21.209), Kant claims that philosophy cannot "achieve scientific evidence" without use of mathematics. See also OP (22.512f., 515).

<sup>177</sup> In a curious passage of OP (22.81), Kant suggests that the parallel postulate admits of *philosophical* proof, proceeding from the analysis of concepts alone. Were this the case, then mathematical construction would *not* be necessary for *a priori* knowledge of determined objects. That said, Kant never provides a method of so-proving the parallel postulate: his comment ever remains a one-off suggestion. Kant struggled with the status of the parallel postulate throughout his career: see Heis (n.d.). Perhaps, for a time, he considered the possibility that it admits of philosophical proof, though this never appears to be advocated in OP.



interpretation might however respond that despite Kant's general pronouncements regarding the necessity of mathematics for *a priori* knowledge of particular natural objects, the specifics of OP cast doubt on his continued adherence to (v) and (vi). In particular, Kant's aether deduction and *a priori* enumeration of the elements appear to be cases where Kant derives *a priori* knowledge of natural science independent of mathematical construction. In the next section, I explain the role of the aether and elements in chemistry. In the course of this discussion, I will dissolve this apparent tension in Kant's philosophy of science and validate the numbered argument from MAN.

### 3. On the Aether and the Anticipation of the Elements

In this section, I contend that chemistry remains rational in OP because Kant retains his account of the chemical elements and laws from the 1780s, which was presented in chapter 2. I explain why neither the aether proof nor the *a priori* deduction of the elements ground a proper science of chemistry, concluding the line of argumentation opened at the end of the previous section. This conclusion bears on Friedman's interpretation of chemistry in OP, for he contends that Kant was more optimistic about *a priori* foundations for chemistry in OP (1992: 164–90). Thus, insofar as is committed to the contention that Kant thinks chemistry to be a *proper* science in OP, my arguments contradict Friedman's interpretation.

Kant consistently maintains that chemistry is “the science of the inner forces of matter” (OP, 21.453). By “inner” forces, as I explained in chapter 1, Kant means those that cause the decomposition or dissolution of matters (DP, 29.117; MAN, 4.530).<sup>178</sup> Physics, on the other

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<sup>178</sup> Girtanner concurs that there are affinities of combination and of decomposition (1792: 8, 11). These chemical operations are distinguished from mechanical divisions by both Kant (MAN, 4.530) and Girtanner (1792: 2f.).

hand, considers “external” forces—those forces whereby matters affect the motion of other matters (MAN, 4.530, 536). As I explained in chapter 2, in the Critical period, Kant adopts a *power* conception of the elements. Kant’s elements—earth, water, air/fire, salt, and phlogiston—“have their origin only in reason,” meaning that they are not empirical concepts, but rather ideas of reason. We postulate the elements as the pure, unconditioned bearers of the fundamental causal powers in order to organize our knowledge of chemistry. The chemical behavior of substances—their expression of *inner* forces—must ultimately be reducible to elemental explanation. Such a power conception of the elements was popular amongst the phlogistic chemists preceding Lavoisier, such as Georg Stahl, who contends that, since we cannot isolate elements in their purity, we must postulate them *a priori* in advance of inquiry.

In contrast, as I explained in the prologue, the Lavoisierian, antiphlogistic chemists defend a divergent *operational* conception of the elements. Lavoisier rejects the preceding views of elements as the ultimate constituents of matter—associated with the Aristotelians, Becher, and Stahl—and conceives of elements as the those substances that are unanalyzable by known processes.<sup>179</sup>

[I]f, by the term *elements*, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them; but, if we apply the term *elements*, or *principles of bodies*, to express our idea of the last point which analysis is capable of reaching, we must admit, as elements, all the substances into which we are capable, by any means to reduce bodies by decomposition. (Lavoisier 1965: xxiv)

Lavoisier’s elements are not the ultimate, pure bearers of properties but are rather those simple substances we isolate in the laboratory. This conviction leads Lavoisier to defend a modified list

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<sup>179</sup> See also Girtanner (1792: 16f.) and Donovan (1993: 163). Note that, as oxygen is the principle of acidity for Lavoisier and the antiphlogistonists, they, in a sense, lapse into the old view (Lavoisier 1965: 65; Girtanner 1792: 65).

of the elements, which includes oxygen, hydrogen, nitrogen, carbon, caloric, light, and so on (Lavoisier, 1965: 175f.). Although water was classically considered to be an element by chemists, Lavoisier (1783) dismissed the simplicity of water on the basis of experimental results. First, Lavoisier demonstrated, following Cavendish, that water is synthesized during the detonation of inflammable air (hydrogen) and dephlogisticated air (oxygen). Second, Lavoisier showed that water decomposes into inflammable air and dephlogisticated air by rusting iron with water in a vacuum. This process results in inflammable air filling the vacuum. Lavoisier understood this reaction to proceed by the dephlogisticated air in the water combining with the iron (oxidizing it), thus releasing free inflammable air into the vacuum. Since water can be decomposed and recomposed in the laboratory, Lavoisier concluded that it is not simple and thus, contrary to his predecessors, that it is not an element (1783: 454).<sup>180</sup>

In Refl 71 (1793–4), Kant demonstrates his acquaintance with these developments by referring to Lavoisier’s elements by their German names, whose coining is attributed to Girtanner (14.502).<sup>181</sup> Though he apparently gives no exhaustive list of the elements, Kant’s partial enumerations in OP largely match those of the antiphlogistic, Lavoisierian chemists: for example, Kant takes oxygen, hydrogen, nitrogen, carbon, caloric, and light-matter to be elements (OP, 22.360, 605).

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<sup>180</sup> As Friedman (1992b: 288f.) notes, Kant demonstrates his exposure to this development in V-Met/Dohna (28.664) and in a 1795 letter to Soemmerring (Br, 12.33f.). In the former passage, Kant claims that water is not an element because it is composite, as Lavoisier contends. *Prima facie*, it may appear that Kant is thereby endorsing Lavoisier’s operational conception of elements. However, given Kant’s discussion of elements in OP (see below), Kant cannot endorse the operational conception of elements. Elements, for Kant, must be *simple* but are nevertheless ultimately bearers of causal powers.

<sup>181</sup> Kant follows Girtanner’s (1792) conventions regarding the names of the elements in this reflection and throughout OP. These naming conventions are also adopted by Gehler (1787–95). See also OP (22.462).

Although this may appear to be a substantial change in Kant's views on chemistry, I contend that he holds fast to his Critical, power conception of elements and denies Lavoisier's operational conception. First, Kant takes the elements to remain the fundamental explanatory basis for chemistry, correlating each with a particular basic moving force of matter. In OP, Kant distinguishes between *matter* (*Materie*) and *materials* (*Stoffe*). Matter, he claims, is singular; there is only one matter that fills the entire universe (22.359ff.). Materials, on the other hand, are diverse and explain the specific variety of matter—that is, those properties that vary amongst given material bodies (states of aggregation, cohesive strength, chemical affinities, pressure, boiling point, etc.).<sup>182</sup> Kant identifies the elements (“*stoicheia*”) with the materials (OP, 22.535), and thinks of these materials or elements as bearers of causal powers. He refers to them as “*complementa virium moventium materiae* [*counterparts of the moving forces of matter*]” (OP, 22.525).<sup>183</sup>

Matter is the outer object of the senses in general insofar as it can be only one and unlimited—in contrast to empty space. Its moving forces as specifically different types of matter are called *materials* (*materies, materie*): parts of matter to which thus also belong specifically different forces and [which] are moving substances (as nitrogen, carbon). (OP, 22.525)<sup>184</sup>

So for Kant, the elements/materials are bearers of particular sorts of moving forces. This conception of the elements shows great continuity with Kant's power conception of elements. Thus, although Kant adopts the particular elements of Lavoisier (including caloric, light, oxygen,

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<sup>182</sup> This point is repeated throughout OP, see (22.90, 360).

<sup>183</sup> Elsewhere, Kant identifies the materials with moving forces (OP, 22.131, 351).

<sup>184</sup> See also OP (22.360, 429, 450, 535).

and so on), he nevertheless retains the older conception of the elements as surrogates for particular causal powers (moving forces) and as the explanatory basis for chemistry.<sup>185</sup>

Second, Kant implicitly rejects the Lavoisierian operational conception of the elements, holding that the elements are postulated *before*, not *after*, scientific inquiry.

Now all outer perceptions are effects of the influence of the moving forces of matter and of the outer object affecting the subject, and, to that extent, merely appearances; thus, they can be given *a priori* as to their formal element. Thus forces can also be thought in matter which are *materials* (that is, substances which belong to the motion of matter and which form the basis of these forces); and physics is a doctrinal system of them. These materials, regarded in their capacity as moving forces, permit of being enumerated *a priori* according to principles: as founded on *attraction and repulsion* (both, however, on penetrating or superficial [force], acting from whole to parts, etc.), coercible, etc. May be enumerated and classified *a priori*, according to principles. (OP, 22.408f.)

Kant maintains in OP that the moving forces of the materials, and thus the chemical elements, may be enumerated not just in the advance of inquiry, but *a priori*.<sup>186</sup>

Although I have shown the continuity in Kant's views on the nature of elements, an issue mentioned at the end of section 2 again arises here. Proper sciences are supposed to be those that have an *a priori* core (MAN, 4.469). One may think that the aether or the enumeration of the elements that Kant suggests constitutes just that kind of pure core for chemistry, making the science proper. Furthermore, one may think that these *a priori* cognitions are just those that witness the falsity of (v) and (vi), above. That is, the fact that we can cognize *a priori* the aether and the elements shows that mathematical construction is *not* necessary for *a priori* knowledge in special science. In the remainder of this chapter, I argue that this modification to Kant's

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<sup>185</sup> Note that the *onus-potentia* framework for the elements found in DP (29.161) is repeated in OP (22.216f.), lending support to my claim of continuity.

<sup>186</sup> Although Kant maintains this, he fails to present any definitive enumeration. At one point Kant oddly suggests that we catalogue the moving forces according to the five senses (OP, 22.326). Elsewhere Kant seems to claim that the system of moving forces has categorial form (OP, 22.406).

account of the elements is largely superficial: his views on chemistry remain consistent with those of the critical period. Neither the aether nor the enumeration of the elements makes a proper science of chemistry possible.

In the course of the transition project, Kant is especially concerned with accounting for the possibility and behavior of attractive-superficial and repulsive-penetrative forces—respectively, cohesion and heat. In early drafts of the transition (the *Oktaventwurf*), Kant claims that such forces are only possible via a medium (*Zwischenmaterie*) that encompasses all bodies (OP, 21.375). This medium is the all-encompassing, omnipresent aether, which makes possible cohesion as well as heat and has a number of other interesting characteristics.

- i. The aether contains all matter in the universe: it penetrates all matter (OP, 21.383).
- ii. The aether propagates in two ways:
  - Progressively as light, and
  - Oscillatory as heat (OP, 21.383).<sup>187</sup>
- iii. The aether is originally expansive (OP, 21.377, 383). All other expansion or space filling is derivative (OP, 21.377, 379f.).
- iv. The aether lacks a number of material properties:
  - It is incoercible (and hence, imponderable) (OP, 21.387f.),
  - It has no aggregative state (OP, 21.383f, 399f.), and
  - It cannot be said to be elastic (OP, 21.383).

Regarding states of aggregation, fluidity is taken by Kant to be original or fundamental (OP, 21.374).<sup>188</sup> The cohesion necessary for fluidity is possible through the vibration of the aether.

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<sup>187</sup> Kant argued for the identity of the light-aether and the heat-aether as early as DI.

<sup>188</sup> Kant thinks of gases as *elastic* fluids.

Solidity is a derived property: Kant conceives of solids as originating from fluids by a quasi-geometrical formation of textures due to the impact of the aether.

The aether also plays a privileged role in Kant's system, explaining the possibility of the moving forces of matter and, thus, the activity of the other elements.

One can also term *caloric* the *basis* (first cause) of all the moving forces of matter, for it is thought as the immediately moving *primary material* (*materia primaria*). All other materials (e.g., oxygen, hydrogen etc.) in contrast, which must first themselves be moved by this material, move as *secondary material* (*materia secundaria*), and are only modes of the latter (e.g. light). And the formation of bodies by specifically differentiated elements produces composite forms, which however, must be subordinated to the principle of the possibility of a single experience, not placed beside it. (OP, 21.605)

So, for Kant, the aether is the primary moving body: depending upon the patient of this motion, different moving forces will be expressed.<sup>189</sup> Whereas the other elements are surrogates for particular moving forces, the aether serves a more fundamental role: it makes possible the expression of the other elemental forces. According to Kant, experience requires that there be a collective unity or absolute whole of the moving forces of matter (OP, 21.225, 230, 585, 601f.; 22.550). These moving forces, however, require a basis, which is none other than the aether. Hence the aether, which makes possible the expression of moving forces, is necessary for the possibility of experience and is thus knowable *a priori* (OP, 21.231, 551; 22.251).<sup>190</sup>

Furthermore, as mentioned above, Kant repeatedly claims that the elements (or moving forces) can be enumerated *a priori*. The enumeration of the elements is supposed to proceed by a series of disjunctive judgments, according to which each combination of alternating disjuncts

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<sup>189</sup> Girtanner, following the chemists of the time, contended that caloric also combines chemically with substances to effect state changes. He takes dissolution to be of three types: dissolution in fluid, dissolution in caloric, and mixed dissolution (1792: 3f.).

<sup>190</sup> Only the aether's role in chemistry and its *a priority* are of concern in this context. The details of the aether deduction are beyond the purview of this chapter.

corresponds to a unique moving force (OP, 22.354, 357, 408f.). So for instance, we may suppose that moving forces are either attractive or repulsive and either superficial or penetrative. These disjunctions leave us with four possible moving forces (attractive-superficial, repulsive-superficial, attractive-penetrative, repulsive-penetrative).<sup>191</sup> In some drafts of OP, Kant contends that the categorial determinations of the aether give rise to the enumeration of the moving forces (OP, 22.325, 378f.).<sup>192</sup>

The *a priori* of the aether and the enumeration of the elements appear not only to add an *a priori* core to chemistry but also to threaten Kant's claims that mathematical construction is necessary in proper natural science (claims (v) and (vi), above). In KrV, Kant distinguishes two routes to *a priori* knowledge: rational cognition from concepts and rational cognition from construction of concepts (A713ff./B741ff.). Belonging to rational cognition by concepts are the judgments of general metaphysics derived in KrV—that is, the conditions of the possibility of experience. So, for instance, the principles of the pure understanding (the principles of the Axioms of Intuition, the Anticipations of Perception, and so on) are *a priori* cognitions derived from concepts. Conversely, mathematical theorems are cognitions that are justified by the construction of concepts. As I showed above, Kant makes key use of this distinction in his argument from MAN that proper sciences must make use of mathematical cognition. His point there is that in proper natural sciences, we need *a priori* cognition: however, the concepts with which we are concerned are *empirical*. Insofar as these are empirical concepts, their deployment is not necessary for the possibility of experience. Therefore, we are unable to derive the requisite

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<sup>191</sup> This strategy is reminiscent of an argument Kant presents for the exhaustivity of the fundamental attractive and repulsive forces in MAN (4.498f.). There he claims that a moving force may either resist or augment motion on a line from a central point; thus, there are only two possible forces, one attractive, one repulsive.

<sup>192</sup> See Förster (2000: 96–9).



*a priori* knowledge from the concepts of a proper science via rational cognition from concepts. The only other option is to derive this knowledge via mathematical construction. Thus, if the aether deduction and the *a priori* enumeration of the elements proceed by rational cognition of concepts, belong to a special natural science, and provide us with *a priori* knowledge of objects falling under an empirical concept, Kant must no longer accept the mathematization condition.

I contend that ultimately these *a priori* components entail no substantial revisions to Kant's views on the application of mathematics and his theory of chemistry. First, neither the aether nor the enumeration of the elements belongs to chemistry. The aether is no mere empirical entity of a special science. Rather, its existence is *necessary for the possibility of experience*: in order for there to be a collective unity of moving forces—which, itself, is necessary for experience—there must be an omnipresent aether that serves as the medium for such moving forces. The existence of the aether belongs not to chemistry—the science concerned with the inner forces of matter—but rather to the transition (itself, a doctrine distinct from any particular science). Similarly, the enumeration of the elements is a component of the transition.

The transition from the metaphysical foundations of natural science to physics must not consist entirely of *a priori* concepts of matter, because that would be merely metaphysics (e.g., where are discussed only attraction and repulsion, as such) also not consist entirely out of empirical representations because so it belongs to physics (e.g., observations of chemistry) rather to the principles *a priori* of possibility of experience consequently to natural investigation, i.e. the subjective principle of schematism of the power of judgment to classify the empirically given moving forces by principles *a priori* as such, and so to cross from an aggregate of the latter to a system as compilation to physics as a system of the same. (OP, 21.362f.)

As Kant makes clear, the concepts of the transition, though *a priori*, are entirely distinct from the *a priori* concepts of metaphysics or the empirical concepts of physics or chemistry. The *a priori* components of the transition—the aether and the enumeration of the elements—make possible a

system of moving forces (OP, 22.149).<sup>193</sup> By presenting *a priori* classificatory categories for the moving forces of matter the transition makes possible a system of natural cognitions, characteristic, for Kant, of science.

Second, a proper science, for Kant, requires *a priori* laws: a proper science of chemistry would thus have *a priori* laws regarding the inner forces of matter. Neither Kant's aether proof nor his *a priori* enumeration of the elements, however, provides such *a priori* laws. As I have observed, these are merely presupposed for the sake of the systematization necessary for transition from metaphysics to empirical natural science. The fact that the aether exists does not entail any particular *a priori* laws about it. The enumeration of the elements only accounts for the *possibility* of the other materials—determining the laws that govern them is a contingent matter for experimental investigation.<sup>194</sup>

Hence, neither the aether proof nor the *a priori* enumeration of the elements threatens Kant's claim that mathematics is necessary in proper natural science. In the argument from the preface of MAN (above), Kant argues that to derive *a priori* laws regarding the *empirical* concepts of a proper natural science, we require mathematical construction. Only rational cognition from construction of concepts yields the *a priori* intuitions necessary in this case. But, as I have shown above, neither the aether proof nor the *a priori* enumeration of the elements produce *a priori* knowledge regarding the empirical concepts of a particular natural science—whether physics or chemistry. Furthermore, neither serves as the derivational ground for *a priori* laws characteristic of proper natural science. Therefore, I conclude that the *a priori* components of Kant's transition neither make chemistry an *a priori* science nor abrogate his claim that

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<sup>193</sup> See also OP (22.377).

<sup>194</sup> Förster (2000: 112) concurs with this point.

mathematics is necessary in a proper natural science.<sup>195</sup> Moreover, my arguments raise difficult questions for those who defend Tuschling's *Mathematikpolemik*: which of the above premises (i–vi) did Kant reject in OP, and where is the definitive evidence that he rejected this premise?

The understanding on offer bears on the Friedman's historically informed interpretation of Kant's conception of chemistry in OP. According to Friedman, in MAN Kant asserts that the forces of chemistry or empirical physics cannot be treated *a priori* because they *specific* (1992b: 239–42). That is, such natural forces—like those of decomposition and dissolution or those that explain cohesion—in contrast to the fundamental forces of attraction and repulsion, *vary* amongst different matters. Since these forces are not universal to all matter, we can have no *a priori* knowledge of them. But Friedman contends that between MAN and OP Kant “found new reasons for optimism: there is a way to comprehend a priori the specific or particular moving forces of matter after all” (1992b: 242). In particular, Friedman argues with the support of a sensitive, detailed discussion of the history of 18<sup>th</sup> century chemistry that progress in pneumatic chemistry, the science of heat, and antiphlogistic chemistry swayed Kant to consider the possibility of a physical, *a priori* chemistry (1992b: 264–90). Though Friedman's interpretation is nuanced and well grounded in the history, his thesis should give one pause, for he does not definitively state whether Kant's newfound optimism entails chemistry's *propriety*. Although Friedman does not explicitly weigh in on this question, he admits that the chemical revolution involves no new mathematization of the science. Rather, he claims that Kant is especially

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<sup>195</sup> That said, as alluded to above, in the 1796–7 *Oktaventwurf*, Kant suggests that state changes may be mathematized by means of the aether. He describes solids as originating from fluids by a quasi-geometrical formation of *textures* (21.395f.). As a fluid body cools, its interstitial aether imparts less motion, allowing for the formation of elementary formations—threads, plates, and clumps—that correspond to the three spatial dimensions and their geometries (*Euthimetry*, *Epipedometry*, and *Stereometry*). I contend that this account is an attempt to mathematize state changes by use of the aether, which would contribute to an account of chemistry's propriety. However, such geometrical descriptions of state changes do not appear in later drafts of OP. Hence, Kant considered the possibility of mathematizing chemistry early in the composition of OP, but ultimately gives up on this project.

impressed by Lavoisier's "thoroughgoing reorganization of chemical classification" (1992b: 339). As Friedman recognizes that Kant attempts no new mathematization of chemistry in OP and argues against Tuschling that Kant held fast to the mathematization condition, he must therefore agree that chemistry remains an improper science in OP. Friedman is absolutely correct that Kant gloms onto the systematicity of Lavoisier's theory of chemistry: I concur that Kant sought *a priori* grounding for this systematicity in OP. But as I have argued, the *a priori* components added to Kant's theory in OP—the aether deduction, the enumeration of the elements—account only for the systematicity of natural science. Therefore, the *a priori* content new in OP belongs not to chemistry but to the science of that accounts this systematicity: the *transition*. Kant is *not* more optimistic for *a priori* foundations of *chemistry*, for such foundations would *still* require the application of mathematics.

Another important moral for Kant scholarship emerges from these considerations. Although in OP Kant sought to accommodate chemical developments into his theory of science, the nature of the aether—the centerpiece of a series of drafts of the transition—is *at odds* with the antiphlogistic view of elements. Had Kant accepted the operationalist conception of elements, the aether would be a merely empirical concept, one that we derive from experience upon discovering it in the laboratory. In virtue of its empirical nature, however, *a priori* knowledge of the aether would consequently require the application of mathematics. Furthermore, as it would be an empirical concept in this case, it could not serve its essential function in OP: making possible the system of moving forces. In the end, Kant's views on chemistry are nuanced: he did not build his transition around new chemical discoveries, as Friedman may have it, but rather sought to integrate these discoveries into a pre-established theoretical system that included already established chemical beliefs.

Finally, aspects of Kant's conception of the elements in OP could have been foreseen given the account of scientific methodology from KrV. As I explained in chapter 2, Kant argues that an essential end of a science is the unification of its phenomena under a single genus (KrV, A648/B678–A653/B681). In KrV and DP, Kant simply lists his five elements as the foundational causal grounds for the science—they share no deeper unity. In OP, as we have seen, he conceives of the elements as modifications of the omnipresent aether. This conception allows Kant to bring a greater unity to the science of chemistry: the elements are unified insofar as they are modifications of the aether.

So, as I have argued, key aspects of Kant's views on chemistry and science remain the same in OP. Kant continues to endorse the power conception of elements, to contend that mathematics is essential to proper science, and to believe that chemistry lacks the features of a proper science. That said, there is a crucial shift in Kant's philosophy of science regarding the source and nature of systematicity. As we have seen, in OP, Kant contends that the systematicity of empirical science must be *anticipated* via the transition project, whereas in KrV, he argues that systematization of a body of cognitions is a goal that we can asymptotically approach, but never achieve. I conclude with the following observations on this modification. First, this shift is *not* necessitated by developments in chemistry that Kant was exposed to post-1786—indeed, as I noted, Kant's views on the elements in OP are explicitly at odds with Lavoisier's operationalist conception of the elements. Second, this is a modification in the doctrine of transition and not in the special science of chemistry, itself. That said, Kant clearly does change aspects of his empirical system of chemistry, integrating many of the chemical developments of the late-18<sup>th</sup> century. However, the propriety and rationality of a science are features of its *metaphysical*

*foundations*: with these metaphysical foundations undergoing no substantial modifications OP, chemistry retains its status.

## CONCLUSION

Scholars commonly depict Kant as a synthesizer, of sorts, of preceding philosophical views. Generally, MAN has been thought of as Kant's attempt to synthesize Newton's physics with a Leibnizian-inspired metaphysics. Recently, due to the historically rigorous works of those such as Buroker (1972), Friedman (1992b, 2013), Massimi (2011), Stan (2013, 2014), and Warren (2001a), the story behind Kant's natural philosophy has become more complicated. Kant's physics is not uncontroversially "Newtonian," rather, it bears traces from other (natural) philosophers, including Boerhaave, Hales, Leibniz, Euler, and Lambert. At the same time, Kant's metaphysics is understood not merely in relation to Leibniz, but also as a complicated reaction to and revision of aspects preceding systems from Wolff, Crusius, Hume, and so on. Nevertheless, the general thesis holds: there is a trend amongst contemporary philosophers to understand Kant's philosophy in relation to his ever-more-complex historical context. As I explained in the introduction, this trend is especially pronounced in works regarding Kant's philosophy of science, and it is this burgeoning tradition that my dissertation naturally complements. I thus conclude my dissertation by describing how it fits into this body of literature.

Following Friedman's seminal work (1992b), in which he contends that the Law of Universal Gravitation can be derived as an *a priori, constitutive* rule from the principles of the understanding, it has been common to emphasize this aspect of Kant's conception of science. For instance, Marius Stan has recently investigated the extent and limits of the constitutive approach in grounding mechanics (2013, 2014). In some ways, the growth of this approach was a reaction to the work of Buchdahl, who emphasized the *regulative* use of reason (Friedman 2013: ix–xi;

Massimi 2013: 393).<sup>196</sup> Buchdahl contended that there is a ‘looseness of fit’ between the principles constitutive of experience—those of the pure understanding—and those of the sciences: the latter cannot be deduced, however indirectly, from the former. This interpretation allows Buchdahl to insulate the principles of the understanding, to an extent, from disconfirmation via scientific theory change. Rejecting the pseudo-Newtonian principles of MAN does not allow one thereby to use *modus tollens* and to conclude that the principles of the understanding are false, for there is no implication from the principles of the understanding to those of physics. While my interpretation of Kant’s philosophy of science is distinct from Buchdahl’s—I, like Friedman, recognize that the principles of physics are derived from the principles of the understanding via the constitutive use of reason—recently the regulative use of reason has been overlooked by scholars investigating Kant’s philosophy of science.<sup>197</sup> As I showed in chapter 2, the regulative use of reason gives rise to genuine causal laws of chemistry that carry something of necessity with them. Reason’s use is not *merely* logical—to search for concepts to plug the holes of the conceptual hierarchy or to connect judgments of a doctrine to the basic laws given by the constitutive use of reason—rather, reason is *productive* in science. The ideas posited by reason make possible genuine explanations; indeed, only explanations based on these ideas, in virtue of the ideas’ objects being unconditioned, can satisfy reason. Furthermore, ideas of reason arise in sciences other than chemistry, like physics (MAN, 4.559)

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<sup>196</sup> This text from Massimi is the introduction to the special section of *Studies in the History and Philosophy of Science* on the relation between Newton and Kant. After introducing Friedman’s constitutive approach, Massimi describes the special issue as “follow[ing] this research path” (2013: 393). For more on the dialectic between Friedman and Buchdahl, see Allison (1994).

<sup>197</sup> To be clear, Friedman recognizes that the regulative use of reason plays an important role in science (1992c). Indeed, he contends that OP is motivated by Kant’s need to connect bottom-up regulative principles with top-down constitutive principles (1992b: 242–64). Nevertheless, I delimit a much larger role for the regulative use of reason in scientific practice than Friedman.



and psychology (KrV, A649f./B677f.). My account of ideas' function in chemistry and their occurrence in other sciences suggests that reason's role in these sciences has been underappreciated.

Furthermore, my dissertation contributes to the recent contextualized research on Kant's philosophy of science since I have shown that his conception of chemistry and his philosophy of science were profoundly influenced by his predecessors. Now, while some have appreciated the influence of lesser-known chemical figures on Kant—especially Carrier (2001), Massimi (2011), and Friedman (1992b, 2013)—the connection between Kant's views and his chemical predecessors' has too been neglected to some extent. When one takes heed of this context, the straightforward, plausible interpretation of chemistry's impropriety, exemplified by Körner and Dussort, is simply and obviously refuted. I showed in chapter 2 that reflection upon this context also helps to clarify important Kantian doctrines, including the positive use of reason and the nature of laws. Moreover, recognition of this influence makes sense of crucial passages in Kant's corpus, such as the passage on laws from KpV and that on the secure path of science from the B-edition preface to KrV. Understanding Kant's version of phlogistic chemistry additionally highlights the continuities between Kant's Critical works on science and OP.

Therefore, Kant's conception of chemistry is a complicated synthesis of influences including Descartes, Newton, Boyle, Hales, Boerhaave, Leibniz, Wolff, Stahl, Lambert, Euler, *and* Kant's own Critical philosophy. But I also claim that our newfound understanding of Kant's hierarchy of the sciences reveals his theorizing on the *nature of science* to be a synthesis of preceding views, especially those deriving from the scientific revolution. According to the arguments of my dissertation, the hierarchy of the science ought to be understood as follows. A science is a collection of concepts and judgments, wherein these cognitions are connected as

*logical* grounds and consequents: that is, the concepts are ordered in a genus-species hierarchy and the judgments are ordered according to their analytic relationships. A rational science is a science whose cognitions are additionally ordered according to *real* ground-consequent relations: that is, they are connected as causes and effects. But, as I explained in chapter 2, to gain *knowledge* of such causal relationships, a rational science equally requires *experimentation*. Finally, as I argued in chapter 1, a proper science is one that makes use of mathematical constructions, or, equivalently, that has *a priori* laws and apodictically certain cognitions.

I contend that each aspect of this conception of the sciences can be found in prominent predecessors of Kant's. In his *Posterior Analytics*, Aristotle offers the idea that genuine knowledge—*episteme*—in contrast to mere opinion—*doxa*—is systematic. He contends that, to know something non-accidentally, one must know its ground and that it follows necessarily from this ground.

We suppose ourselves to know anything absolutely and not accidentally after the manner of the sophists, when we consider ourselves to know that the ground from which the thing arises *is* the ground of it, and that the fact cannot be otherwise. Science must clearly consist in this, for those who suppose themselves to have scientific knowledge of anything without really having it imagine that they are in the position described above, while those who do possess such knowledge are actually in that position in relation to the object. [¶] Hence it follows that everything which admits of absolute knowledge is necessary. (Aristotle 1901: 4)

One must, of course, be wary, for “science” and “scientific knowledge” in the translation are *episteme* and its forms in the original. So, to be clear, Aristotle is not here presenting a philosophy of science in the contemporary sense. He is rather simply claiming that the highest form of knowledge, or absolute knowledge, is *demonstrative*, where the premises to a demonstration must be “true, primary, immediate, better known than, anterior to, and the cause of, the conclusion” (Aristotle 1901: 4). In the remainder of this chapter, Aristotle explains the

meaning of the components of a demonstrative system, including thesis, hypothesis, axiom, and definition.

With Scholasticism's enshrinement of Aristotle's views, his conception of *episteme* transforms into *scientia*.

In early modern philosophy *scientia* is an honorific term. It refers to knowledge or understanding of truths in the light of principles or causes. *Scientia* is systematic knowledge of truths, truths "deducible" from principles. It is not simply knowledge-that, but knowledge-why, and not simply knowledge-why, but knowledge-why that unifies whole classes of truths known. Again, *scientia* is not merely knowledge why truths *happen* to be true. Instead, it is knowledge that the relevant truths cannot *but* be true given the relevant causes or principles. So it is knowledge of truths within a framework that makes their truth look necessitated by the underlying principles. Described like this, *scientia* is an ideal of both pre-modern and early modern philosophy. (Sorrell 2010: vii)

Kant, like many of his early modern forerunners, thinks of *scientia* as characterizing an epistemic ideal and not as characterizing a particular set of topics or methodologies (as the contemporary notion of science may). Indeed, Kant's term for science, *Wissenschaft*, has similar connotations of systematization and is treated synonymously with *scientia*. But to this bare notion of a systematic body of cognitions, Kant integrates the lessons from his Critical philosophy and the scientific revolution.

First, Kant distinguishes between grounding a piece of knowledge in a *logical* ground vs. a *real*, or causal, ground. Kant thought this distinction to address a major defect in prior rationalist metaphysics: by conflating these grounds those such as Wolff and the early Kant were led to believe that real knowledge of the world can be derived purely logically. Such inferences gave rise to the excesses of metaphysics criticized in the Transcendental Dialectic of KrV. The distinction between these sorts of grounds then gives rise to two kinds of sciences: those that connect their cognitions logically (sciences) and those that connect their cognitions causally (rational sciences).

Kant recognizes, however, that to gain knowledge of the specific causal rules of a rational science, one requires empirical data: in particular, to learn the causal laws that govern nature, one must experiment. Kant was convinced of the necessity of experimentation by his natural philosophic forerunners. While, in the B-preface of *KrV*, Galileo, Torricelli, and Stahl receive credit for their recognition of the necessity of experimentation in science, Kant equally could have credited Boyle, Newton (at least, Newton of the *Opticks*), or Hales. As I argued in chapter 2, especially section 5, Kant recognizes that the postulation of causal powers that ground a science requires supplementation from experience. Though we can postulate a fundamental power of the mind, it does no explanatory work for us if we cannot verify that the powers of the mind *are* truly unified in the manner proposed. To do so, we must conduct experiments.

Finally, Kant concurs with Aristotle and many of his early modern forerunners by thinking that absolute certainty is characteristic of genuine science.

Despite the divergence of approach among thinkers of the seventeenth and eighteenth centuries, there is widespread agreement that scientific knowledge is apodictically certain. And this consensus cuts across most of the usual epistemological divides of the period. For instance, Bacon, Locke, Leibniz, Descartes, Newton, and Kant are in accord about this way of characterizing science. They may disagree about how precisely to certify the certainty of knowledge, but none quarrels with the claim that science and infallible knowledge are co-terminous. (Laudan 1983, 114)

Kant initially describes proper science as that sort of science that has *a priori* laws or apodictically certain cognitions. In the preface to *MAN*, he writes that “What can be called *proper* science is only that whose certainty is apodictic; cognition that can contain mere empirical certainty is only *knowledge* improperly so-called” (4.468), but according to Kant this certainty must derive from the application of mathematics. In this case Kant’s views again reflect those of his natural philosophic predecessors. The idea that mathematics is characteristic of science or natural knowledge was defended by authors such as Newton and Descartes. Descartes,

in particular, also held that certain knowledge of the sensible world is mathematical. But this view that mathematics is essential to natural knowledge finds its most elegant presentation in the words of Galileo.

Philosophy is written in this grand book—I mean the universe—which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth. (Galileo 1957: 237f.)

Of course, Kant has his own idiosyncratic views on mathematics and hence on its application in natural philosophy (as I argued in chapter 1). Nevertheless, the idea that mathematics is essential to scientific practice is captured by Kant in his hierarchy of the sciences. The concepts of a proper natural science are, for Kant, mathematically constructible, and in virtue of this we can achieve apodictically certain natural knowledge. As he argues, to cognize things determined by some empirical concept—as the things of a proper science are—we require intuitions. The only mode of cognizing that allows us to achieve *a priori* knowledge on the basis of intuitions is mathematical construction. Thus, in order for a science to achieve *a priori* and certainty, it must utilize mathematical construction.

Hence, Kant's hierarchy of the sciences is a complicated synthesis of a variety of sources. Kant takes from the Aristotelian doctrine of *scientia* the idea that scientific knowledge is systematic and apodictically certain. His philosophical insights commit Kant to the idea that there are two sorts of systems of nature: those that connect their cognitions logically, and those that connect them causally. He takes from Boyle, Newton, Stahl, and others the idea that experimentation is necessary for knowledge of causes. From those such as Descartes, Galileo, and Newton, Kant learns that the application of mathematics is required in natural philosophy.

As I explained in chapter 1, applying mathematics in natural science is no simple task because of Kant's idiosyncratic conception of mathematical construction. Nonetheless, given metaphysical validation for the use of mathematics in science, *a priori* and apodictic certainty are thereby possible. Therefore, at the highest level of science, we can achieve the end of Aristotelian *scientia*: absolute, certain knowledge.

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