Review of *Kant's Construction of Nature*

Chris Smeenk*†

Michael Friedman, ***Kant's Construction of Nature: A Reading of the Metaphysical Foundations of Natural Science***. Cambridge: Cambridge University Press (2015), 646 pp., $37.99 (paper).

Michael Friedman's *Kant's Construction of Nature* provides a thorough reconstruction of Kant's *Metaphysical Foundations of Natural Science*. In this slender volume, published in 1786, Kant used the resources for characterizing experience and cognition developed in the first *Critique* to account for the central empirical concepts of Newtonian physics. The text is cryptic even by Kantian standards. *Kant's Construction of Nature* elucidates the text, with extensive discussion of almost every passage, drawing on detailed knowledge of Kant's scientific and philosophical context. Friedman's admiration for Kant animates the text; while acknowledging possible challenges to puzzling or obscure passages, Friedman always provides a careful, often ingenious, Kantian reply. Although some of Friedman's readings may inspire controversy, *Kant's Construction of Nature* clearly sets a new standard for a systematic understanding of the text and its central arguments. In doing so, it considerably augments Friedman's influential case in favor of reading Kant in light of his engagement with natural philosophy. Although I lack the space and expertise to explore the matter fully here, Friedman's reading of *Metaphysical Foundations of Natural Science* will open up new lines of discussion regarding the *Critique*, much as his earlier *Kant and the Exact Sciences* has influenced subsequent scholarship.

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*To contact the author, please write to: Department of Philosophy, 3148 Stevenson Hall, University of Western Ontario, London ON N6A 5B8, Canada; e-mail: csmeenk2@uwo.ca.

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I focus on one major theme of *Kant's Construction of Nature*: Why did Newtonian natural philosophy need metaphysical foundations? Roughly put, Friedman takes *Metaphysical Foundations of Natural Science* to establish how Newtonian science can determine laws of nature that are necessary rather than merely hypothetical. The necessity of these empirical laws derives from their relation to what Kant calls the "pure part" of mechanics, which includes the necessary a priori truths of metaphysics and mathematics, in conjunction with the phenomena. Explaining how this works requires showing how the mathematical concepts of Newtonian physics apply to phenomena: "[Kant] aims . . . to explain, step by step, how the fundamental *empirical* concepts of [Newton's] theory acquire their quantitative (measurable) structure and thereby become amenable to a mathematical (rather than merely metaphysical) a priori treatment" (33; cf., 90, 237, 567).

This step-by-step construction is carried out over four sections of the *Metaphysical Foundations of Natural Science*, structured in accordance with the table of categories, as Kant shows how the quantitative structure required by Newtonian physics applies to the empirical concept of matter. This leads to a "construction of nature" in the sense that central concepts such as mass and momentum are accounted for as empirically measurable magnitudes, built up from "matter as the movable in space." The outcome of the construction is a description of phenomena incorporating necessary causal laws, such as Newton's law of gravity. The structure of the text highlights parallels with the *Critique*, but it is also convoluted, as elements of Newtonian physics are developed piecemeal and without quantitative detail. Although *Kant's Construction of Nature* is not a commentary, Friedman follows Kant's division into four main parts, bracketed with introductory and concluding chapters. One of the strengths of Friedman's treatment lies in how effectively he ties together the disparate discussions scattered through Kant's text, elaborating on several technical issues; another is the depth of historical scholarship reflected in how masterfully Friedman describes Kant's critical engagement with Leibnizian metaphysics and his response to mechanical philosophers.

The influence of Newton's *Principia* is evident throughout the *Metaphysical Foundations of Natural Science*. Newton characterized the aim of natural philosophy as the discovery of the fundamental forces of nature from the phenomena of motion. For this to be a sensible aim, he had to establish how motion can be comprehended as "due to forces" at all, by specifying the relationship between trajectories and the force(s) responsible for them. Newton regarded mechanics as the exact science of the generation of physical trajectories, as specified by the Laws of Motion. Any trajectory must be described as a curve through space and time, with respect to some chosen relative space. Newton famously further argued that the distinction between inertial (uniform, rectilinear) and accelerated motion drawn in the

Laws of Motion requires "absolute motion," defined in terms of space-time geometry that cannot be reduced to relations among bodies. For a trajectory described in a relative space, accelerations may not always be due to physical forces, whereas for absolute motion the trajectories are fully determined by the sum of physical forces acting on a body. Many traditional questions are irrelevant to pursuing this austere conception of natural philosophy, which prioritizes the category of quantity. The quantitative features of a force are essential to the inferential connection with motions, but its physical source or mechanical underpinning are not. Similarly, Newton does not provide an explicit definition or account of the nature of bodies. The *Principia* treats bodies quantitatively in terms of their mass, a measure of acceleration in response to impressed force.

From his earliest writings on natural philosophy, Kant argued that Newtonian natural philosophy—characterized as mathematical or geometrical—had to be supplemented by metaphysical foundations drawn from the Leibnizian tradition, moving beyond the category of quantity to include causality, substance, and community. The questions that such foundations would address in Kant's view differed from the complaints of earlier critics of Newton, some of whom sought a "metaphysical" underpinning of Newtonian mathematics in the sense of a mechanical account of gravity and the nature of bodies. Kant did not take metaphysics to involve the type of hypothetical reasoning that Newton had rejected; instead, it could contribute to natural science by accounting for the applicability of mathematics and the status of empirically discovered laws.

Making this contribution requires giving what I call "empirical constructions" of the concepts of Newtonian physics. These bear a subtle relationship to geometrical constructions that proceed mathematically in pure intuition. This becomes clear already in the phoronomy, in which Kant proves a proposition regarding the composition of motions. Motion in one sense—for example, that of a triangle in a Euclidean proof—is carried out by the imagination in pure intuition. How does this relate to the perceived motion of an object (sec. 6)? The phoronomy combines mathematical and empirical concepts of motion: the proof of composition proceeds entirely in pure intuition, without appeal to laws of motion, yet Kant's introduction of a relativity principle at this stage signals a connection with empirical motion. We can experience empirical motion, provided that a body and the space in which it moves are both perceived, but Kant's principle states it is arbitrary whether we attribute motion to the body or the space itself. Roughly put, Kant aims to address a question that he takes Newton to ignore: How is it that we can treat concepts like velocity and force as mathematical magnitudes? In the preface of the *Metaphysical Foundations of Natural Science*, Kant strikingly argues that the applicability of mathematics depends on the existence of a priori principles (as opposed to merely empirical laws) comprising the "pure part" of a proper science. One aim of the *Metaphysical Foundations of Natural Science* is to characterize the pure part of mechanics, establishing its a priori necessity. An interpretative challenge is then to specify the sense in which the "empirical constructions" related to the general features of matter fit into Kant's conception of the "pure" part of any proper science and its relation to mathematics.

To understand this challenge, I first briefly summarize Kant's "construction" of quantity of matter, following Friedman. Kant's discussion addresses tensions that arise between different aspects of Newtonian mass. There are three conceptually distinct things measured by quantity of matter: (1) the density of an impenetrably filled region, (2) the response to impressed force (inertial mass), and (3) the gravitational acceleration produced at a given distance (active gravitational mass). Kant rejects a "mechanical" conception of matter, which treats bodies as composed of rigid impenetrable atoms, in favor of a dynamical account, which explains matter's space-filling properties in terms of a balance between fundamental forces of repulsion and attraction. Leibniz and others had criticized atomism on a variety of grounds, for example, that the impact of rigid atoms would lead to discontinuities in motion. Rigid bodies are not compatible with Kant's treatment of motion, since the change in motion at impact cannot be described in accord with the phoronomical composition of velocities. By contrast, changes in motion due to repulsive moving force, which add increments of velocity directed away from a force center, augment the earlier description by specifying the cause of velocity changes. Kant further argues that the repulsive force inherent in matter has to be supplemented with a fundamental force of attraction. A body's finite extent results from the balance between an inherent repulsive force and a counteracting attractive force.[1] This force of attraction has to be regarded as an immediate action of matter on matter, rather than a by-product of pressure or contact action, according to Kant, since it "contains the ground of physical contact." Kant's dynamical account of matter is the only treatment of "how matter fills space" compatible with the mathematization of motion established in the first step of his construction and with the categories of causality and substance as they are treated in the critical philosophy.

Yet recovering Newton's concept of quantity of matter in the second sense—as a measure of response to impressed force—requires further work. There is no connection between the spatial geometry of bodies determined by the balanced dynamical forces and their trajectories through space and time, and there is no means for comparing or composing the magnitude of quantity of matter for different kinds of matter. Kant emphasizes that the only generally valid measure of the quantity of matter is based on the quantity of motion (momentum). The link between spatial extension and a body's

1. See Smith (2013) for further discussion of this "balance argument."

motion in response to forces depends on Kant's three laws of mechanics, governing the communication of motion between bodies. Kant explicitly relates each law to the *Critique*'s analogies of experience. Friedman argues that Kant's mechanical laws are sufficient to establish that the quantity of matter of a given body can be estimated by velocity exchanged with another body in a center of mass frame. Determining the quantity of matter of bodies using a balance similarly depends on conservation of momentum, Kant's third law of mechanics.

The goal of Kant's construction is, however, to establish quantity of matter as a universally measurable quantity (e.g., 380). For Newton, attributing quantity of matter to celestial bodies depends on several empirical arguments. On Kant's approach, by contrast, the crucial question regards the link between the dynamical forces inherent in matter and the laws governing the communication of motion; the latter provide the empirical grounds for measuring quantity of matter needed to complete Kant's construction. Kant's account of the connections among these three features of mass depends on his characterization of forces; for example, Friedman explains the connection between 2 and 3 as a consequence of Kant's treatment of gravity as a penetrating force. Friedman takes Kant's construction of "quantity of matter" to show that these connections are needed for a truly universal measurable quantity of matter.

This, I hope, provides a sense of one of Friedman's contributions, namely, providing a detailed account of these constructions that builds considerably on Kant's laconic treatment. The *Metaphysical Foundations of Natural Science* leaves obscure central topics such as the relationship between Kant's laws of mechanics and conception of force to their Newtonian counterparts; for example, Kant's second law holds that "every change in matter has an external cause." Kant apparently recovers an analog of Newton's second law indirectly, on the basis of the treatment of the composition of velocities in the phoronomy and his restriction that forces act in the direction of the incremental velocities they generate (sec. 28). This is an instance of a question that can be formulated more generally: If we take the geometric style of the *Metaphysical Foundations of Natural Science* seriously and regard it systematically, as a set of proved propositions, how does its content compare to other formulations of Newtonian mechanics? Questions regarding theoretical equivalence are not Friedman's focus; he emphasizes instead the contrast in how this content is regarded—that in Kant's case, for example, constructions are required to introduce mathematical quantities. Yet his discussion raises a number of questions regarding the actual content of Kant's system that may be fruitfully addressed in further research. For example, to my mind whether what Friedman calls Kant's "Copernican conception" of motion makes an important contribution, by contrast with Newton's views, turns in part on the equivalence between their conceptions of force.

I now turn to two brief critical comments. First, how are these "empirical constructions" of Newtonian concepts related to mathematical constructions, and in what sense are they "empirical"? What is at issue here is, more generally, the status of the laws and concepts of scientific theories and the proper role of mathematics.[2]

Kant takes mathematics as exemplifying the possibility of synthetic a priori knowledge. Central to his account of mathematical cognition is an account of "mathematical construction," which aims to capture mathematical practice and clarify the status of its results. A geometrical construction, for example, proceeds by pairing definitional claims regarding a figure with an immediate representation of that figure, in pure intuition. This allows Kant to maintain his general claim that concepts have content insofar as they bear an appropriate relation to intuition, in the case of mathematical concepts. Alongside this account of mathematical reasoning, Kant's transcendental idealism leads to a distinctive account of the applicability of mathematics. The results established via geometrical constructions in pure intuition necessarily apply to the objects of our experience because space is the form of outer intuition; objects as we represent them in space must be in accord with Euclidean geometry.

It is tempting to assimilate Kant's empirical constructions with mathematical constructions. Kant's remarks in the preface suggest that a proper science necessarily involves mathematics because it requires concepts constructed a priori in intuition—a characteristic feature of mathematical cognition. Friedman argues against this reading because it fails to acknowledge the need for the pure concepts of the understanding to play a role alongside a mathematical representation in pure intuition in establishing the objective reality of a concept (secs. 10, 19). In the case of a dynamical force of repulsion, for example, the effects of a repulsive force on the motion of an approaching body can be represented in pure intuition, as a composition of motions. Yet the attribution of causality to the force requires bringing in the analogies of experience, which have a conditional character, allowing one to infer the existence of an effect given the cause but not to construct the effect a priori. In the *Critique*, Kant warns against falling "into mere phantoms of the brain" (A222/B269) in trying to establish the real possibility of empirical concepts, such as force, purely a priori. Avoiding this mistake requires acknowledging the contingent, empirical aspect of physics, which in Kant's system is reflected in the contrast between the mathematical principles of pure understanding and the dynamical principles, namely, the analogies of experience. This contrast is reflected in Kant's treatment of the laws of mechanics as instantiations of the analogies of experience. The

2. See Heis (2014) for a more detailed critical assessment of Friedman's position on this point.

applicability of mathematics to empirical concepts such as quantity of matter cannot be achieved on the basis of a mathematical construction alone but requires a combination of mathematical and dynamical principles in constituting objects of experience.

Does this position provide a persuasive analysis of the a priori necessity of the pure part of mechanics, compatible with the empirical content of the concept of matter? There seems to be a tension between the necessity attributed to the laws and their constitutive role in relation to measurements. Kant treats the laws of mechanics as instantiations of the Analogies of Experience, and their necessity derives from the more general principles. Yet it is difficult to see how the content of the laws can be elucidated or understood on the basis of this approach. The instantiations of general metaphysical principles are only quite indirectly connected to the mathematical structures of Newtonian physics. Roughly speaking, then, the argument for the a priori necessity of the laws seems insufficient to determine their content; however, the arguments that do bear directly on their content seem insufficient to establish that they are a priori. The applicability of mathematics requires, on Friedman's account, the elucidation of universally applicable measurement procedures for new theoretically defined quantities. Quantity of matter, for example, is well defined by virtue of how it appears in the laws. The laws themselves do not have empirical content independently; rather, they are required to make sense of the new quantities, so that observations or experiments can be legitimately brought to bear on them. This line of thought focuses on the constitutive role of the "pure part," and it is natural to expect the laws to be formulated mathematically given their role in underwriting measurement. Yet it is tempting to pry this aspect of Kant's empirical constructions apart from the necessity attributed to laws (as with Reichenbach and other neo-Kantians). I am not claiming that this is a plausible exegesis of Kant; rather, the question is what in Kant's position prevents him from acknowledging an empirical component in the laws of mechanics that is compatible with their constitutive role.

The second comment regards assessing the *Metaphysical Foundations of Natural Science* in light of post-Newtonian developments in mechanics and reflections on the foundations of mechanics by practitioners (such as Euler and d'Alembert). Friedman does not situate Kant's contributions with respect to these issues in detail. As a matter of Kant's intellectual biography, it may be the case that the *Metaphysical Foundations of Natural Science* aims to account primarily for the applicability of mathematics in Newton's *Principia*. But in terms of understanding the strengths and limitations of Kant's approach, it is worth considering how it might apply to Enlightenment mechanics, which had a much broader scope than Newton's *Principia*. Euler and others extended mechanics to cover problems regarding elastic, deformable, and rigid bodies, and systems with constraints.

In light of these developments, will the foundational principles Kant identified in the *Metaphysical Foundations of Natural Science*, like other supposedly necessary principles identified at a given stage of inquiry, fall by the wayside as inquiry progresses? Kant's dynamical theory of matter is a significant step toward treating bodies as continua. Yet his formulation of mechanics does not seem to capture all that is needed for such bodies. The mechanics of true continua differ significantly from that appropriate for point masses. The motion of a point mass can be characterized fully by a trajectory, but extended bodies have further degrees of freedom related to their orientation—needed to specify, for example, the spin of a baseball. The mechanics appropriate for describing such bodies requires principles governing their angular momentum.[3] In light of these changes, more needs to be done in assessing what form a Kantian foundation for Eulerian rather than Newtonian mechanics might take. Is it possible to provide, in effect, a "merely technical" revision of Kant's project, replacing the "pure part" of mechanics with laws that have been suitably formulated with a different concept of matter as the starting point? Successful completion of this project would reveal that Kant had chosen a more parochial starting point than he realized but would otherwise leave much of his project intact.

I speculate that pursuing this line of thought would lead to a more thorough reevaluation of Kant's foundations of physics. For it is not clear that Kant's system is compatible with a different "empirical" concept of matter, such as that of an extended deformable body with internal stresses. The laws appropriate for such bodies have a different form than the laws of mechanics Kant derives from the analogies of experience, and it is unclear how to obtain the appropriate laws while staying true to Kant's approach. This raises the concern that the status of the "pure part" of the science of mechanics may be quite different in the simple case of point-particle mechanics, by contrast with later developments. The attempt to apply Kant's approach to subsequent developments in mechanics would put further pressure on the tension identified earlier between the a priori character of the laws and their constitutive role. It is natural to regard the laws of subsequent mechanical theories as articulating what is required for the measurement of various quantities to make sense, yet they have a much less direct connection to the Euclidean properties of space. I am speculating that extending Kant's approach would lead to a more empiricist position on the foundations of physics, akin to Helmholtz's empiricist conception of geometry. Helmholtz recognized that "facts" about the free mobility of rigid bodies lay at the basis of geometrical reasoning, in the sense that the practice of spatial

3. Stan (2014) argues that Kant's dynamical conception of matter is in fact incompatible with his treatment of Newtonian mechanics due to problems regarding angular momentum.

measurement implicitly presupposes their validity. But he also acknowledged that the utility of geometry so conceived is an empirical question. Similarly, different accounts of the foundations of mechanics would be taken to articulate the "facts" about bodies that lay at the basis of physical reasoning, leaving open the question whether it is useful to describe empirical situations in these terms.

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