Once More Unto the Breach : Kant and Newton

Michael Friedman: *Kant's Construction of Nature. A Reading of the* Metaphysical Foundations of Natural Science. Cambridge: Cambridge University Press, 2013, xix+624 pp. ISBN: 9780521198394.

Watching the stream of papers and monographs on Kant these days, one might think the Sage of Königsberg cared little for anything besides the metaphysics of modality and the nature of obligation. That is a far cry from the real Kant, whose first and last writings, nearly six decades apart, were on the foundations of exact science, with steady, robust contributions to that field every decade or so. The zenith of his dialogue with classical physics was about two thirds into his career, and culminated in the masterful *Metaphysical Foundations of Natural Science* of 1786, henceforth '*Foundations.*'[1] Michael Friedman's book is the latest, most valiant attempt to tackle it. In form and proportion, it evokes Aristarchus of Samothrace annotating Homer; in aim and content, it recalls Porphyry explaining Aristotle: six hundred pages of commentary on the most difficult hundred pages in all philosophy of physics. Friedman set himself the task of making transparent sense of every utterance in a small book that, by a combination of difficult matter, historical distance, and taxing prose, is often impenetrable. He succeeds by any measure, with a poise that belies the titanic efforts it cost him. In the process, he sets a new standard for interpreting Kant's philosophy of science, and early modern natural philosophy more broadly. He clarifies opaque passages with enviable ease, and deploys at length the technical prowess that made him legendary among specialists.

The mode of presentation is *commentarius perpetuus*, thus its outward shape is dictated by its *explicandum*, viz. by the architectonic of Kant's *Foundations* with its four chapters. However, that obscures the book's argument structure.

[1] Numbers in parentheses denote page numbers or sections in Friedman's book. Numbers prefixed by '4:' denote pages in the Academy Edition of *Foundations*.

There are four main themes: a) Kant's engagement with Newton; b) with the broad Leibnizian tradition before him in Germany; c) with the 'mechanical' philosophy; and d) the relationship between *Foundations* and the First Critique. These result in four main claims, with secondary arguments coalescing around each. I explain them below, then I outline an agenda, and I eventually note an obscurity. Regrettably, theme [**D**] is too rich and complex to treat here profitably, given my space limits. I take comfort in knowing that others will soon give it due attention elsewhere. It is sure to open a new line of investigation for Kant scholars.

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Theme [**A**] is the most exciting track of argument, at least for readers of this journal. Friedman's broad methodological vantage point is contextualism—the hermeneutic principle that, to make the most sense of the target author, one must read her in the context of the science of her time not some timeless, ahistorical scientific enterprise. In Friedman's well-known view, the natural science in the title of Kant's opus is "Newton's theory of motion" (89), the gravitational dynamics in Books I and III of the *Principia*. Friedman's key thesis is that Kant follows *and* corrects the Briton. He follows him, by singling out for philosophical attention precisely Newton's key notions 'velocity,' 'force,' 'quantity of matter,' and 'true motion.' And, he corrects him in two respects. (**i**) Newton takes it for granted that his basic concepts have a *magnitude structure*, to wit, they are additive properties—hence mathematics, or *Mathesis magnitudinum*, applies to them as features of *bodies*. He either assumes it blankly, as with instantaneous velocity;[2] or defends it empirically, by appealing to pendulum experiments so as to conclude that 'quantity of matter' tracks weight, which *is* additive, as entailed by Archimedean hydrostatics and Galileo's theory of free fall. (**ii**) Likewise, Newton assumes that some of his key notions, e.g. 'true motion,' are well-defined empirically—hence the mathematical models in his Book I have physical import. But, that must be shown not presumed, maintains Friedman's Kant. Moreover, these concepts rest on mistaken metaphys-

[2] Newton's kinematics is entirely implicit, and parasitic on the geometry of conics (the trajectories of the bodies he studies) and a heavily geometrized calculus, in which velocity is the local tangent to a given curve.

ics, which he will correct. In sum, for Kant the central philosophical problem of Newton's science is to explain the application of mathematics to nature:

> "What is required, rather, is an explanation of how it is possible to apply mathematical construction to empirically given properties of matter step by step, beginning with the most fundamental such property – motion – and then proceeding to others such as density, mass, and force." (237)

To see how Kant proceeds, take (i) above. He grounds the assumption that key Newtonian concepts have a magnitude structure in two ways.

[**i.1**] For velocity, he gives an a priori procedure—a construction in pure intuition—whereby two 'motions' are 'composed.' That is, he displays a geometric proof of the parallelogram rule for the vector addition of instantaneous linear velocities.[3] Hence, velocities are additive *quanta*, and so 'motion,' the first basic property of body, is a magnitude. Thereby, the applicability of mathematics to kinematics is philosophically guaranteed. The same goes for 'force,' which is likewise demonstrably a magnitude: forces always induce accelerations, or *velocity* increments, *collinear* with them. So, they too are additive attributes of body, controlled by the Parallelogram Rule, hence are magnitudes. Then forces are fit for treatment by mathematics.

[**i.2**] The case of mass is considerably more subtle and difficult. First, that body has mass is not some a priori given but an empirical fact. Thus, Kant could not ground the additivity of mass by any construction in pure (=non-empirical) intuition. Second, in the age of Kant and Newton, mass was linked inextricably to two other concepts, viz. 'density' and 'quantity of matter.' Thereby, the status of mass becomes connected intimately to deep issues about the ultimate structure of body. Now Kant in *Foundations* does have a matter theory, his 'Dynamics,' which he opposes to Newton's and others'. Kant's matter is a physical continuum endowed with two essential forces, repulsion and attraction. A clever inference, nowadays called a Balancing Argument, allows Kant to derive a notion of density, and also to show that it is constructable, though from essential forces assumes as *given*, hence a posteriori. This victory comes at a cost. Kant cannot show that density has a ratio structure: he cannot allow density comparisons between different stuffs. Hence, he ultimately can-

[3] This sounds bizarre to modern ears: *we* know that addition—for elements of vector spaces, in linear algebra; for vectors at different locations, in calculus on manifolds—is set down axiomatically, and any attempt to prove it is circular. The Enlightenment did not, and hoped to 'prove' it from various premises. This raises deep issues that I cannot address here.

not use density *directly* to show that inertial mass is additive. Thus, to ground the applicability of mathematics to corporeal mass, he takes refuge in Mechanics. There, in three Propositions, Kant links conceptually 'quantity of matter' to inertial mass (*the* causal attribute of matter), to weight, and to momentum. The latter is needed because quantity of matter is not constructable, so it must be "estimated" empirically from "the quantity of motion at a given speed," i.e. from the changes in *momentum* it causes in interactions (4: 537). Kant's 'third law of mechanics' governs these changes, and it entails that (measurable) velocity exchanges are inversely as the masses undergoing them. These results underwrite weighing, the terrestrial act of inferring masses from their (virtual) velocity increments, which are directly as the respective arms of the balance. Crucially, Kant's point that all matter is attractive allows us to "project" weighing "outwards into the heavens" (359). That is: we may extrapolate to cosmic scales—as Newton did—the practice of measuring masses from their velocity changes near the Earth's surface. Our license to do so is Kant's argument linking weight to gravitational mass through his concept 'quantity of matter,' the metaphysics of substance in which he embeds it, and his law of action and reaction (§§ 25, 28).

As to **[ii]** above: Newton assumes a concept of true motion, distinct from the merely apparent motions we see bodies exhibit. Critically, Newton defines it as change of place in absolute space, effected over a stretch of absolute time. Just as importantly, he defines 'true motion' *before* he introduces his three laws of motion. And yet, neither absolute space nor time metaphysically distinct from body is given to the senses. Thus, from Friedman's perspective Newton simply assumes that 'true motion' has empirical content, whereas that is just what Kant aims to justify. To do so, Kant takes drastic action. He rejects *Newtonian* absolute space and time, giving instead a broadly empiricist account of true motion, in two steps. First, he lets his three laws of mechanics *define* it *implicitly*: it is the kinematic quantity of bodies that satisfies Kant's laws, in particular his Equality of Action and Reaction. The latter entails that bodies have Kant-true motions relative to a distinguished inertial frame, in which the mass center of their interaction is at rest. That *material* frame is *Kantian* absolute space. Second, he shows how it must be "constructed," i.e. located in the physical world. Essentially, the 'construction' is an iterative approximating procedure, in which one starts with an arbitrary frame, and—guided by Kant's modal categories and his three laws—one moves on to ever better material substitutes for a genuinely inertial frame. The procedure is open-ended, or terminates in an empirically-unreachable frame, viz. the mass center of the physical universe, "a kind of surrogate, as it were, for Newtonian absolute space" (353). That is really Kant's absolute space, which is thus an idea of reason, not a concept of a given thing. The true motions of bodies are their motions relative to that single, global frame. Judging about every single body that its true motion is relative to *it* 'unifies' our experience of moving objects: it

> "embeds all the correspondingly different appearances of motion within a single and unique description relative to the common center of gravity of the entire system." (496)

More importantly, as the frame's origin coincides with the mass center, we must—at all subsequent steps in the procedure—measure the masses of bodies with which the subject body interacts. Because of that, Newton's law of gravity (a universal interaction) and Kant's law of action and reaction turn out to be essential elements for the 'construction' of true motion, which is thereby shown to be a concept of experience.

Readers of Friedman will have seen the distant origin of this idea in the path-breaking Chapter III of his *Kant and the Exact Sciences* (1992), or *KES*. However, his new account has changed in notable ways. Whereas in *KES* true motion was defined by *Newton's* three laws, Friedman now claims it is *Kant's* three 'mechanical laws' that define it implicitly. This shift came in reaction to intervening discoveries by Eric Watkins and others that Kant's laws were born in a medium deeply influenced by Leibniz not Newton, so close attention to their content will reveal that they are not fully equivalent to Newton's three laws.[4] Just as importantly, Friedman has now spelled out in great detail what *KES* just outlined: for instance, Kant's threefold account of 'phenomenological' judgments (§§ 32, 34). As direct evidence—that Kant *throughout* his Phenomenology engages with Newton's competing account of true motion—is sometimes scant, Friedman has bolstered his latest case by a sharp, relentless effort to uncover structural similarities between Kant's and Newton's respective arguments. Reasonably, likeness of structure counts as indirect evidence, for Friedman (in addition to the *textual* evidence he produces for his account). To that end, he undertook also a re-reading of *Newton's* argument in Book III, so as to highlight, before he gets to Kant, the salient (for his interpretation)

[4] See especially Watkins (1997). Friedman also acknowledges this reviewer's Stan (2013).

aspects of Newtonian procedure in that Book.[5] Not least, there is now a sophisticated, highly ingenious elucidation of Kant's utterly cryptic words on terrestrial spin and the nature of true rotation: read it for yourself (§ 33).

[**B**] Equally interesting is Friedman's case that Kant sought to reconcile a "broadly Leibnizian" metaphysics with Newton's science (17, 21). That too is a theme he had broached in *KES* first. In the years since then, some fine scholarship by Eric Watkins, Vincenzo de Risi and others has taught us much about the contour and details of Leibniz's posterity in Germany, and Friedman has made the best of those researches.[6] As he sees it, already the young Kant was a 'broad Leibnizian' bent on accommodating Newtonian science, and in *Foundations* he continues that project, this time by radically reinterpreting both Leibniz and Newton (168). The mark of Leibniz is seen in Kant giving primacy to material substance; activity, or causal efficiency, as its criterion; and making 'force' an inherent attribute not just an episodic occurrence, as *vis impressa* is in Newtonian dynamics (334-5). (And also, though Friedman does not claim it, in the young Kant asserting that motion is relative.) Just as Leibnizian, it seems, are the basic laws that govern these substances: the Principle of Sufficient Reason, and a peculiar version of the Equality of Action and Reaction. In the 1780s, Kant refurbishes this scaffolding en masse. Now all material substance is composite, none is simple; the PSR recedes far into the background, replaced by conservation principles and the Law of Continuity (400-2); and space is no longer a *phaenomenon bene fundatum*. (Neither is body, which it was for Leibniz.)

In fact, the revision is so drastic that we might wonder what, if anything, is genuinely Leibnizian about this updated Kantian framework. Consider what it has: three absolute no-noes for Leibniz—real action at a distance, genuine inter-body causation, and the denial of simple substance. Then it has a tenet—activity as the mark of substance—that Newton too had endorsed, contra Descartes.[7] Friedman will say, even the Critical Kant retains a Leibnizian distinc-

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[5] For instance, Friedman now makes clear that, in his initial description of the "Phaenomena"—the apparent motions of the five primary planets and Jupiter's satellites—Newton leaves open the choice between Tycho (for whom the Earth rests) and Copernicus-Kepler (for whom it moves). This is analogous—much, though not fully—with Kant's starting his constructive procedure (of locating the chief inertial frame) with a choice between taking the Earth to rest and taking it to move (relative to objects falling toward it).

[6] See De Risi (2007) and fn. 4 above.

[7] In his unpublished *De Gravitatione*, where Newton infers that space is not a substance, for substance is active whereas space is dynamically inert. See Newton 2004: 21.

tion between noumenal and phenomenal substance. True. Kant's 'unschematized' concept of substance has all the features of Leibnizian *substantia simplex*. What we can *know* by well-grounded theory, however, is 'schematized,' 'phenomenal' substance alone, and that has all the *non*-Leibnizian features above. Whether this result fits the label 'Leibnizian metaphysical foundation' is an open question so far.

[**C**] Quite new, and very instructive, is Friedman's analysis of Kant's critical stance toward the 'mechanical philosophy.' That term was always, and still is, fluid. Moreover, to denote its adherents Kant himself uses the phrase 'the mathematical investigators of nature.' (He has in mind sometimes Descartes, sometimes Euler and Lambert, and even Newton. Had he known more of d'Alembert, he would have rebuked him too.) Thus, it is more enlightening to see the themes that Kant engages with: the status of impenetrability, and the existence of 'hard bodies,' or rigid objects in nature.

Kant objects to some mechanical philosophers taking impenetrability—the 'filling of space,' in his parlance—for an analytic property of matter. *Sed contra*, he argues, a body is impenetrable not just by existing at some location, but by exerting *force*, an 'original repulsion' common to all matter. Hence, impenetrability is derivative, or secondary to force. It follows from Kant's inference (the Balancing Argument I noted above) that *extension* is likewise derivative. A body's shape and volume is really its equilibrium configuration, the *result* of its essential forces—repulsion and attraction, its Kant-primitive attributes—balancing each other. This contrasts sharply with the mechanical philosophy, in which extension was the basic trait of body par excellence.[8]

As to 'hard bodies,' Kant's rejection is not unprecedented. Leibniz and his followers, e.g. Johann Bernoulli in *Discours sur les loix de la communication du mouvement*, had already denounced them—though Leibniz, Janus-faced as ever, denied rigidity to Newton yet asserted it to Denis Papin. Their official charge was that rigid objects violate the Law of Continuity: hard-body colli-

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[8] Friedman does not remark upon this, but here as elsewhere Kant rediscovers, unbeknownst to him, a Leibnizian theme. In the unpublished fragment "On Body and Force, against the Cartesians" (1702), Leibniz had argued that extension, far from being primitive, results in fact from the "repetition," or "spreading out" of "resistance, diffused throughout the body" (Leibniz 1989, 250f). Kant is, of course, much more sophisticated in his account, and more modern too. A mark of his superiority over Leibniz is that he clearly distinguishes between 'dynamical' resistance (to compression), the physical basis of impenetrability; and 'mechanical' resistance to acceleration, the ground of inertial mass. Moreover, his account of force is closer to Newton than to Leibniz.

sion takes an infinitesimal time to result in a finite change of speed. Thus, the bodies' velocities make an instantaneous 'leap,' so to speak, whereas *natura non facit saltum*. Kant's critique is in the same vein, but is more subtle. His point is that, in collision, rigid bodies switch from motion to a "complete lack of motion" at the point of impact (4: 486). As Friedman helpfully explains (§2), that kind of rest is not a well-defined quantity, hence is not constructable, or representable in the *geometric* kinematics of *Foundations*. In modern analytic terms, the body's velocity function is not differentiable at that point.

Having dismissed rigidity, Kant eventually moves to banish empty space, on several fronts (511-9). Thereby, he subverts completely the mechanical-philosophical model of body as an assemblage of rigid parts and pockets of empty space. In its place, he offers the notion of body as a continuum, deformable in all interactions and subject to functions differentiable everywhere—hence governed by his 'Law of Continuity.' Even more remarkable is Kant's vigorous pushback against the widespread early modern denial of action at a distance, sometimes motivated by the pithy dictum, 'a body acts only where it is.' As Friedman makes limpid, Kant shows how rash that denial was, and how treacherous the intuition behind the dictum (205ff).

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With *Kant's Construction of Nature*, the long-standing topic of Kant's philosophical treatment of Newton's dynamics appears closed. While future scholars may quibble with this or that, minor aspect of Friedman's construal, it seems very unlikely that anything novel and robust can be added to his account. It is time to turn our attention to other aspects of Kant's natural philosophy, while keeping Friedman's contextualist stance, which I applaud. If I may, I would suggest a twofold agenda.

First, we ought to look beyond Newton, to founding fathers of mechanics closer to Kant's own time. For instance, Kant's 'mechanical' laws and his 'phoronomic' theorem are strikingly similar to d'Alembert's laws, whose mechanics is notoriously more powerful than Newton's. Likewise, we know that Kant took a keen interest in Maupertuis' Principle of Least Action. Lagrange in 1760 turned it into the basis for a powerful dynamics—the close precursor of Hamilton-Jacobi theory—and so it would be important to study whether Kant's doctrine can absorb a least-action principle. Even more importantly, we ought to look at Kant and Euler more closely and fully. Friedman does examine Kant's reception of Euler's hydrostatic model of ether pressure—luckily, Kant used it just to explain cohesion, not gravitation, as the great Swiss had done initially—and his wave theory of light. However, Euler's more important exploit was to turn the 'Newtonian,' force-based vector approach into a general theory of classical mechanics. The relevance of *that* for Kant's foundations remains to be explored.

Second, there are systematic issues outstanding. It is time to ask about the explanatory scope of Kant's mechanical foundations. At its widest, classical mechanics is a theory of extended deformable bodies. However, Kant's Phoronomy grounds merely the mathematical treatment of entities with three degrees of freedom, viz. points not bodies. More is needed from Kant: specifically, a fully general concept of body motion—namely, transplacement—and kinematic axioms for it. Once we do that, we might discover that Kant's mechanical laws need strengthening (in content or number), as might his Phenomenology if it is to be general.[9] And, we may wonder whether Kant's denial of rigidity will ultimately let him ground a mechanics of constrained systems. In the Enlightenment, notably by d'Alembert and Lazare Carnot, constrained motion was modeled as generalized hard-body impact, in which the body would 'lose' some of its impressed motion—namely, the component normal to the constraint—as a result of collision with a rigid object (e.g., an inclined plane). That seems a non-starter for Kant, who begins *Foundations* by ruling out hard-body collision (§2). But, can he do better?

I am getting at the philosophical question, is Newton's theory merely one (albeit great) application of Kant's framework in *Foundations* or its *sole* possible instantiation—and, if so, what is needed to extend the framework suitably? To be sure, Friedman himself has shown, elsewhere, how to extend it—by enlarging its metric and inertial aspects—so as to accommodate post-Euclidean and relativistic theory. But, there is still the task of generalizing the framework in a *classical* setting, in order to explain mechanical phenomena not covered by Newton's theory, though they occur at Galilean speeds.

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[9] In Phenomenology, Kant articulates a concept of true motion. But, that notion has a generalized analogue in continuum mechanics, where it is needed to constrain the range of admissible constitutive relations between stress and strain. It is the concept of mechanical objectivity, often called 'material frame indifference.' Its exact content is still being debated. For a sample, see Frewer 2009.

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Friedman's proverbial clarity of exposition shines throughout his book, and yet understanding failed me once. I present here a question I have been struggling with as I read *Kant's Construction of Nature*, and hope the reader will have better luck. Does Kant have a view about the metaphysical nature of true motion? Or is his Phenomenology a reflection on just the epistemology of its discovery? In other words: does Kant have a view about what true motion is, or consists in—about the constitution of motion *in re vera*, as Descartes had put it? Or is his treatise really just about which kinematic quantities of body are objectively ascertainable?[10]

There is evidence, in *Foundations*, that Kant's interest is really in the first disjunct. Much of his talk about motion being 'relative' is in fact an expression of relationism, the view that the nature of true motion is to be a special relation between bodies. In Kant's own words, it is an "active relation of matters in space" (4: 488, 545). Moreover, Kant's denial of Newton's absolute space is a dialectical move in a conversation about the metaphysics of motion not its epistemology. Thus, it must be prior to any epistemological qualms Kant must have had about Newton's own definition. After all, it long precedes his move to Transcendental Idealism. (Kant switched to relationism in the 1758 *New Doctrine of Motion and Rest*.)

However, Friedman's interpretation tends to emphasize the second, epistemological disjunct above. In exquisite detail, he lays out how Kant thinks we turn motion into an object of experience, or an objective quantity measured by impeccable procedures. Skillfully, he explains how Kant uses dynamical laws and his *epistemic* categories of modality to infer to true rotation from apparent Coriolis deflection; and to true accelerations from measurable masses. (He spends less time detailing his claim that, for Kant, the definition of true motion is implicit in his three 'mechanical' laws.[11])

[10] Modern philosophies of space-time physics focus heavily on the latter. However, in the Seventeenth Century the most heated debates concerned the former. Moreover, the early moderns—except Huygens—embedded their doctrines of space in a mixture of ontology (in modern parlance) and philosophical theology; that was 'metaphysics' for them. As Friedman has shown elsewhere, Kant purges the doctrine of space of its earlier theological underpinnings.

[11] I am not sure what Friedman's evidence is for that thesis.

If Friedman is right, then we must conclude that Kant chose to engage merely with one paragraph—the last out of fourteen, and sole epistemological part—in Newton's celebrated Scholium to the Definitions, where he defines true motion and *justifies* his definition. Specifically, Newton makes clear that any acceptable definition of true motion—whether his or of his opponents, the relationists—must meet certain conditions of adequacy. They are the "properties, causes, and effects" of true motion (Newton 2004: 64-70). That is why he embraced absolute space: no relationist account, he argued, can satisfy his conditions above. Why did Kant ignore this key Newtonian point—it takes up over half of the Scholium—about the metaphysics of true motion? And, if he did not ignore it, what is his answer?

Friedman might retort that, irrespective of Newton's demand, Kant does have a metaphysics of true motion. It is the privileged 'active relation' I mentioned above. If so, there are three issues outstanding. One: does it satisfy Newton's 'properties, causes, and effects'? Two: what does it really consist in—what are its relata? Officially, Kant claims they are the moving body and a material 'space,' or frame. However, read closely his account of 'necessary motion'—the acme of his Phenomenology—and you will see that it is a relation between two bodies, not a body and a frame. Three: if Kantian true motion is a relation to a frame, the latter must be truly inertial. Only Kantian absolute space is so, in his system, and it is a regulative concept. Then what sort of concept is 'true motion' for Kant—regulative or constitutive? Is it both?

This leads me to a second, more poignant question. I hope Friedman will ask it too, seeing as he is in the best position to answer it. His Kant appears to straddle uncomfortably the early and late modernity. By letting his laws define a concept of true motion, Kant would appear to presage the doctrines of Carl Neumann, Ludwig Lange, and other like figures in the twilight of classical physics. Moreover, Kant's constructive procedure starts with frames that obey Newton's Corollary *Six*, not Five—which puts Kant closer to the later Einstein, of GTR not special relativity. And yet, by having his absolute space denote a *single* frame not an equivalence class, Kant seems to have remained in thrall to the 17th century idea that true motion is true velocity *not* acceleration. Thus, my question is: what prevented Kant from seeing Galilean relativity? What kept him from having our breakthrough insight that it must be a constraint on the dynamical laws themselves, and so that true motion must really be true acceleration? After all, Kant does see quite clearly that his 'dynamical' forces, of attraction and repulsion, are Galilean-relative. They 'impart' the *same* 'motion' whether the acting body is at rest or in uniform translation. Then why did he fail to see that the same holds of force in general, and so that *no* single frame may be privileged over and above its Galilean brethren?

At any rate, my puzzles above should not detract in any way from the great merits of *Kant's Construction of Nature*. The book is insightful, rigorous, thorough, clear, and interesting on every page. Most of it is unprecedented discoveries, relative either to the field or to his previous results. Friedman has again earned the right to claim for himself Horace's *Libera per vacua posui vestigia princeps*. There is patient enlightenment for the novice, a new road map for the scholar, and much subtle delectation for the inveterate connoisseur. It opens up many new vistas for Kant scholars, historians and philosophers of science, and students of early modern thought. Above all, it is immensely enjoyable, improbably so for its heft. How many monographs can do that?

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