CHAPTER EIGHT

REBELLIOUS WOLFFIAN: KANT'S PHILOSOPHY OF MECHANICS IN 1758

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Some leading scholars have seen a "conversion to Newton" by Kant around 1755, followed by a "commitment to Newtonian physics for the rest of his life."[1] In flavor, this alleged Newtonianism ranges from strong to tame, but it affects large swathes of Kant's natural philosophy: it colors his theory of matter, speculative cosmology, and methodology of science. I argue below that his conversion left intact some key areas in his early philosophy of physics, strongly marked by Wolff. In *New Doctrine of Motion and Rest* (NL) of 1758, Kant proffers a view amounting to an *internal* revision of Wolff's philosophical mechanics—not a Newtonian theory, as one would expect.[2] Though brief and terse, his essay is rich: it outlines a theory of true motion, a model of interaction, a priori dynamical laws, and an effort to ground mechanics in philosophy. It is also seminal: nearly all his views in *NL* resurface, transfigured yet familiar, in the mature *Metaphysical Foundations of Natural Science* (MAN). This prompts us to reassess the scope of Kant's loyalty to Newton; and it shows

[1] M. Schönfeld, *The Philosophy of the Young Kant: the Precritical Project* (Oxford, 2000), 75, 79. Similar views espouse V. Mudroch, *Kants Theorie der physikalischen Gesetze* (Berlin, 1987), 78; P. Guyer, *Kant* (London, 2006), 162; B. van Fraassen, *The Empirical Stance* (New Haven, 2002), 8; P. Kerszberg, "On Kant's transcendental account of Newtonian mechanics," in M. Bitbol, P. Kerszberg, J. Petitot (eds.), *Constituting Objectivity: Transcendental Approaches to Modern Physics*, (Berlin, 2009), 66.

[2] Cf. I. Kant, *Neuer Lehrbegriff der Bewegung und Ruhe, und der damit verknüpften Folgerungen in den ersten Gründen der Naturwissenschaft* (Berlin: Georg Reimer, 1912), 13-26. I follow convention and quote from Kant's work by citing the volume and the page number in the German Academy edition.

post-Leibnizian elements persist in his philosophy of physics.

Elsewhere, I laid out the logical makeup of Kant's *NL* in detail.[3] Here, I curtail that analytic approach in favor of a diachronic look: I summarize his results in the essay, and use them to stress its post-Leibnizian backdrop, continuities with his earlier thought on force, and influence on his later views.

I- Kant's 'New Doctrine of Motion'

NL is an argument in three parts: a theory of motion; a critique of "force of inertia;" and an application of his theory to collisions. These topics may seem unrelated, but they form a single, sustained argument, as I will show. The 'new doctrine' announced in the title is Kant's theory of motion and its a priori laws. A theory of motion is a *philosophical* account of the concept 'true motion.' It aims to answer two questions: (1) whether bodies have a *true* motion besides their *apparent* motions relative to observers; (2) if they do, what does it consist in—is it (2.1) motion relative to space distinct from matter or (2.2) a special type of motion relative to other bodies? Descartes, Huygens, Newton, Leibniz and Berkeley long struggled with them, a sign of how difficult the problem is.[4]

Kant seems to begin with an attack on both (2.1) and (2.2). First, he examines some likely contenders—the Earth, the Sun, the fixed stars—for the rank of privileged body (or system) relative to which *all other* bodies might move *truly*. He finds them wanting on various grounds, then quickly dispatches (2.1), the view that true motion is translation in a "mathematical space, empty of all creatures, as a container of bodies."[5] He concludes abruptly:

> …there is something lacking in the expressions 'motion' and 'rest.' I

[3] See M. Stan, "Kant's Early Theory of Motion: Metaphysical Dynamics and Relativity," *The Leibniz Review* 19 (2009), 29-61.

[4] Briefly put, Huygens answered 'no' to (1), at least as far as straight-line motion was concerned; hence he did not try to answer (2). Leibniz's response to the two questions above remains a matter of scholarly controversy. Descartes, Newton and Berkeley answered 'yes' to (1), and gave divergent answers to (2). For Descartes, a body's true motion was relative to the bodies surrounding it and regarded as quiescent; for Newton, it was translation in absolute space; for Berkeley, it was motion relative to the frame of the fixed stars. The best account of early modern theories of motion is in R. Rynasiewicz, ""By Their Properties, Causes and Effects:" Newton's Scholium on Time, Space, Place and Motion," *Studies in History and Philosophy of Science* (1995), 133-153; 295-321.

[5] NL 2:17.

> should never use them in an absolute sense, rather always respectively [*respective*]. I should never say that a body rests, without adding with respect to which things it is at rest; and should never say that it moves without at the same time naming the objects with respect to which it changes its relation.[6]

This is ambiguous. It could mean the denial of (1) above, ergo the claim that bodies do not have true motions; or it could be a variant of (2.2).[7] The latter is true, it turns out: Kant *does* accept that bodies have true motions [*wahrhafte Bewegung*], but drastically qualifies that view. For him, true motion is *not* a *property* of single bodies: it is meaningless to ask of *individual* bodies whether they move or rest. Kantian true motion is an *irreducible relation* between material bodies: if a body may be said to move truly, it is always with respect to another body.

Still, a body changes its kinematic relations to many other bodies as it moves; which one is its true motion? In response, Kant singles out its relation to that body with which it *interacts*. Inquiring into the true motions of bodies, he alleges, is a "question about the effect [*Wirkung*] that the two bodies exert on each other."[8] Hence, their relation *to each other* is privileged, because it has mechanical consequences. This relation, their true motion, is "mutual," i.e. symmetric: if a body A moves respective B (in an interaction), then B also moves respective A. Further, A and B each has a share [*Anteil*] in the relation that is their true motion. Kant then invokes a kind of principle of sufficient reason to claim that their shares of true motion are equal:

> …tell me if one can infer, from what happens between them, that one is at rest and only the second moves, and also which of them rests or moves. Must we not ascribe the motion to both, namely in equal measure? Their mutual approach may be attributed to the one just as much as to the other.

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[6] NL 2:17.

[7] The terms 'absolute' and 'relative motion' are fundamentally ambiguous, and care must be taken to disentangle their exact meanings, so as to prevent deep confusion. 'Absolute motion' may mean either (1) *true* motion, distinct from merely *apparent* motions or (2) motion with respect to immobile, or *absolute*, space distinct from body. In turn, 'relative motion' may have either the weak sense of (1) *true* motion as a special type of motion relative to other bodies; or the strong sense of (2) the *denial* that bodies have true motions over and above their *apparent* ones. A subtle analysis of these equivocations is in R. Rynasiewicz, "On the Distinction Between Absolute and Relative Motion," *Philosophy of Science* (2000), 70-93.

[8] NL 2:18.

Ergo, when two bodies interact, they move equally—but respective each other. An example follows; Kant's paradigm is a telling choice, it will transpire: *inelastic impact with a body at rest*. Start with an observer who sees a body A move uniformly toward B at rest, which it impacts frontally.[9] According to Kant's 'new doctrine,' B only *appears* to rest; in fact, it is in true motion relative to A. To measure these motions, he takes their relation of "mutual approach," which he interprets as their *relative speed*. The bodies share it equally; yet the share of each is not a speed but a *momentum*, or mass times speed.[10] Hence, the two collide with equal 'motions,' i.e. momenta with respect to the center-of-mass (CM) of their impact.

Kant takes for granted that any moving body has a 'force' [*Kraft*] of motion whereby it can effect changes in the mechanical state of bodies in its path. From his analysis above, in impact two bodies *always* have equal (true) motions; ergo, they collide with equal force: "both move toward each other … the one with the same force as the other."[11] Being equal, these forces "cancel each other out": as a result, the bodies come to mutual rest. In his doctrine, true motion is a basic relation between interacting bodies. The relation is active: by partaking in it, two bodies act on each other; it is symmetric: both move respective each other; and the two relata share it equally. Moreover, a body's share of true motion also measures its '*moving force*' by which it interacts with the other body.

Laws of motion. With his doctrine in place, Kant infers two claims.[12] One is that, in any 2-body impact, both bodies *truly* move—respective each other—so "it is impossible for a body to approach another one absolutely at rest." The second asserts, "in impact, action and reaction are always equal." He calls them 'corollaries,' to signal that they follow directly from his doctrine.[13] But their *content* and *role* makes it clear that they are laws of motion, or claims about motions and forces in interactions. Kant means his first corollary to replace the Law of Inertia; this is less alarming than it sounds. Not that he denies the Law to be true—

[9] By 'frontal impact,' I mean a collision between two homogeneous spheres moving uniformly along their 'line of centers,' the straight line between their centers of mass.

[10] Tacitly, Kant acknowledges that mass is dynamically relevant, or makes a difference for the mechanical efficacy of bodies.

[11] NL 2:19. Next quotation: *ibidem*.

[12] NL 2:19.

[13] I reconstruct Kant's inference to his 'corollaries' in Stan, *Kant's Early Theory*, 43f.

he knows it is; he just thinks it is *not provable a priori*, unlike his corollaries. It is merely "the law of a general phenomenon known through experience and whose cause we do not know, hence should not hurry to ascribe it to an inner natural force."[14] The meaning and role of that 'inner natural force' Kant rejects here will soon become clear.

More interesting is his second law, of equal action and reaction. Recall that, earlier in *NL*, Kant had proved that whenever two bodies collide, they meet with *equal* true motion (no matter how they *appear* to move, if at all). Tacitly, he assumes that a body in motion has 'moving force,' equal to the body's true motion.[15] It follows that any two bodies collide with equal force. By its 'force of motion,' a body acts on another through impact; and its action is proportional to the 'force' it has. If two bodies act with equal 'force,' their action on each other is equal. Ergo, action equals reaction—where 'reaction' denotes the contrary action of another body, in a collision. Allow Kant his tacit premises about 'force,' and he can derive a law of action and reaction a priori.

Yet Kant's law is *not* Newton's Third Law; they differ notably. For one, *Lex Tertia* holds of impressed forces; Newtonian 'actions' *are* the impressed forces of the Second Law in the *Principia*.[16] But Kantian 'actions' and 'reactions' are *effects* of 'moving forces,' which are properties of bodies in true motion.[17] Another difference is in their range: Newton's law is true of impact, pressure, and action-at-a-distance forces; Kant's discussion makes clear that his a priori law holds only "in the impact of bodies." Not least, Newton's *Lex Tertia* is part of *three* laws of motion, whereas Kant has only two.

Grounding collisions. With his new concept of motion and two 'corollaries' in place, Kant goes on to apply them. The payoff, it turns out,

[14] NL 2:22.

[15] Some technical details are in order. Quantitatively, Kant in *NL* measures a body's motion by its scalar momentum, or mass times speed. He also takes, implicitly, a body's 'force of motion' to be measured by its scalar momentum. Remember that, from his doctrine of motion, when two bodies collide they have true motions relative each other, with respect to the center-of-mass (CM) of their collision. But, relative to CM, their momenta are *always* equal. Hence, their motions, forces, and actions are equal to each other, respectively.

[16] Cf. Definition 4: "Impressed force *is the action* exerted on a body to change its state either of resting or of moving uniformly straight forward."—Isaac Newton, *The Principia*, trans. I. B. Cohen and A. Whitman (Berkeley, 1999), 405; my emphasis.

[17] That is to say, Newtonian forces are identical to Newtonian actions; Kantian forces and actions are related as cause and effect. Thus Newton and the early Kant have divergent views about the ontology of mechanical agency.

is that now he can "explain the laws of impact according to the new doctrine of motion and rest." In his usage, the term 'laws of impact' denotes a set of kinematic rules describing how the velocities of two bodies change when they collide. At the time, there were two such sets, depending as one took the bodies to be elastic or inelastic. To apply his results, Kant chooses inelastic impact; he suggests it is because inelastic collisions are dynamically simpler than elastic ones; the latter, he believes, can be modeled from his doctrine by adding "elastic force" to it.[18] I shall discuss Kant's first of two examples: a body A of mass 3 and speed 5 strikes B of mass 2 at rest (relative to an observer).

The grounding, or "explanation of the laws," is a threefold act. First, Kant re-describes the situation above; his new theory of motion legitimizes the re-description. Rest and speed 5 are only kinematic ways in which A and B *appears* to an observer. In *fact*, he argues, A has speed 2 *respective B*, and B has speed 3 *respective A*: by his *Lehrbegriff*, the true speeds of two bodies are relative to each other, inversely as their masses. Second, by his second 'corollary' Kant predicts the outcome of the impact: A's action equals B's reaction, so both come to rest, *respective each other*. This prediction is wholly a priori, not justified by induction. Third, Kant explains how this outcome *appears* to the observer: post impact, she sees the bodies move jointly past her with residual speed 2, i.e. the speed of the observer's space *before* impact, relative to the space of the bodies' true motions.[19]

This focus on collisions and their kinematics is bizarre if one expects Kant, now three years into his conversion to universal gravity, to ponder the foundations of *Newton*'s mechanics. His next, polemic move in *NL* makes his Newtonianism even less credible.

II- *Vis inertiae* refuted

NL is a rhetorical thrust-and-parry, with Kant now assailing key tenets of a view he seeks to defeat, now strengthening defenses. Having outlined a theory of motion, he goes on the offensive, and claims that "force of inertia" [*Trägheitskraft*] is illicit in metaphysical dynamics. He mounts a two-pronged offensive, charging that it is both unneeded and incoherent.

[18] As he puts it, his philosophic-dynamical analysis holds "if [the bodies] are assumed to have struck one another directly and all elastic forces are disregarded." Cf. NL 2:23f.

[19] NL 2:24f. More plainly put, the observer sees A and B move together at the speed of the CM-frame (speaking loosely) relative to the 'lab frame.' *This* initial speed is not affected by the interaction of A and B, hence remains constant.

To show that force of inertia is redundant, he takes it to denote "an inner force within bodies" *at true rest*. This qualification is crucial—and revealing, we will see. Another premise in Kant's attack is his new doctrine's first corollary. If the premises are granted, his objection is unanswerable: when two bodies collide, both move truly (relative to one another); ergo, no body is ever truly at rest; hence, there can be no 'force of inertia' in *quiescent* bodies.

If the objection above depends on results in *NL*, the charge of incoherence is self-standing, though he still takes 'force of inertia' to be a trait of bodies *at rest*. A resting body, Kant reasons, is balanced on all sides: if an external force acts on it, an equal and opposite force counters the former; and if the body has an inner tendency to move in some direction, it is balanced by an equal and opposite tendency—or else the body would move instead of staying at rest. But the opponents he targets understand force of inertia as a 'striving' [*Bestrebung*], i.e. a "motion or endeavor contrary to the direction" of the other, approaching body in a collision. So, he objects, champions of *vis inertiae* think of a quiescent body as both balanced and imbalanced, both resting and striving to move: an incoherent view.

Continuity and collision. Next, Kant assaults the same idea—that resting bodies have a force of inertia—from a different angle. To subvert it, he targets an alleged premise in its defenders' account of how *vis inertiae* explains velocity changes in impact: the "physical law of continuity." A tenet that goes back to Leibniz, the law has it that "a body never communicates its force to another all at once, but only such that it transfers it throughout the infinitely small degrees in between rest and a determinate speed."[20] Those who believe a moving body could ever collide with another one *truly at rest* must presuppose this law. Kant reconstructs their account thus: if a body were truly at rest, it would only have *vis inertiae*, a passive force to "resist motion;" a moving body, endowed with 'moving force,' must first overcome this resistance before it can set the resting one in motion. To move the stationary, it must defeat its 'force of inertia' by transferring to it as much 'moving force' as the resting has to resist. This transfer of force ceases when the two bodies reach the same velocity, hence they move jointly after impact.

Yet, Kant points out, for this model to explain, one must assume that transfer of force to the stationary is by degrees, continuously from rest to a velocity equal to the moving body's leftover 'motion.' In other words, one must assume the Physical Law of Continuity. Reject the law, and the model it supports—impact as a clash between moving force and force of

[20] NL 2:22.

inertia—collapses. Ergo, *vis inertiae* is indefensible as a *dynamical factor in explaining collisions*. This is not to say, of course, that the Law of Inertia might be false; for Kant it is still a fact that bodies do not self-accelerate. But if the Physical Law of Continuity is false, he reasons, then it is untenable to say that resting bodies have a 'force to resist,' a *vis inertiae*. And the Law *is* false—or at least devoid of any evidential support: "the most famous physicists will not even accept it as a hypothesis; for it could never pass for anything better, as it cannot be proved."[21] Thus, the 'force of inertia' stands refuted.

Kant censures the 'physical law' of continuity in *NL* chiefly as a tactic to weaken even further the case for a 'force of rest,' the passive *Trägheitskraft*. He knows that Leibniz originated this law; but who is really the target of his offensive?

III- Wolff's a priori mechanics

In *NL*, Kant takes on absolute space, action and reaction, force of inertia—all topics at home in the *Principia*. Is this not evidence that his aim is to revise the basis of Newton's mechanics? I submit that it is not: this reading would make Kant look confused and ineffectual. First, his critique of absolute space is cursory and unoriginal; and it is part of a wider move to reject *in toto* the idea of a global frame of reference for the motion of all bodies. Newton's absolute space is only a version of this idea. Second, Kant's early law of action and reaction is much narrower than Newton's analogous principle; and, unlike it, it does not rest on impressed force. Third, the force of inertia that Kant refutes is the 'force of rest,' not Newtonian inertia, i.e. the power to resist changes in *state of motion*: if directed at Newton, his objections fail miserably. I offer that Kant in *NL* aims to correct *Wolff*'s mechanics, which differs from Newton's on some key points. Seen in this light, Kant's objections begin to look insightful and his solutions clever. Given my space here, presenting Wolff's entire doctrine is not feasible; so, I will selectively sketch those parts affected by Kant's critique.[22]

[21] NL 2:22.

[22] The structure and details of Wolff's metaphysical dynamics remains largely unexplored territory. General expositions of his system are M. Campo, *Cristiano Wolff e il razionalismo precritico* (Milan, 1939); J.-P. Paccioni, *Cet esprit de profondeur: Christian Wolff, l'ontologie et la métaphysique* (Paris, 2006); J. Ecole, *La métaphysique de Christian Wolff* (Hildesheim, 1990). On the relationship between Wolff's cosmology and Leibnizian dynamics, see Ecole, "Cosmologie wolfienne et dynamique leibnizienne," *Les ètudes philosophiques* 19 (1963), 3-9;

Wolffian philosophical mechanics is a mixture of conceptual analysis, deductive inferences from ontological premises, and empirical results. Its core is a doctrine of body, forces inherent to it, and a priori laws of force. A body is a finite volume endowed with "matter" and "active force."[23] Matter, in turn, is "extension possessed of force of inertia"; Wolff calls it a "principle of resistance to motion in bodies," hence "a passive force." By its force of inertia, "a body resists all change." The claim is equivocal; still, Wolff is clear that *vis inertiae* is a principle of resistance. Body also has a principle of acting—by effecting changes in other bodies; this is their "active force," *vis agendi*. He insists that active force "adheres to local motion," and so decides to call it "motive force," *vis motrix*.[24] This notion is likewise ambiguous: (i) in virtue of it, a moving body strives to change *its* place; and (ii) a body *in motion* has *motive force* whereby it acts on *other* bodies by changing their inertial state—e.g., from rest to motion or from some velocity to another. The latter is a key claim, well worth our notice: Kant too admits it unchallenged and makes it part of his mechanics. Wolff is regrettably obscure on the *measure* of motive force in his mechanics. He makes it clear that, in a body, it is proportional to its mass; and also that velocity "determines the state" of active force.[25] This suggests he might take active, or motive, force to be equal to *ms* or $m\mathbf{v}$.[26] But he is also a staunch advocate of Leibnizian *vis viva*, whose measure is mv^2, as *the* measure of 'force' in moving bodies. We are hard pressed to tell which of these estimates—*ms*, mv^2 or $m\mathbf{v}$—he ultimately endorses.

Wolff's *vis inertiae* demands a closer look. Though he calls it a force of "resisting change," he fails to say whether he means only changes in *momentum*—as Newton's mechanics asks—or *any* bodily change in general. This makes it hard to say that his *vis inertiae* is the same as

A.-L. Rey, "Diffusion et réception de la dynamique: la correspondance entre Leibniz et Wolff," *Revue the synthése* (2007), 279-94.

[23] Cf. Chr. Wolff, *Cosmologia Generalis*, editio nova (Frankfurt, 1737), §§ 122, 131, 138. Next three quotations: *ibidem*, §§ 141, 130, 132. By 'local motion,' Wolff means motion understood as change of place [*locus*].

[24] Wolff, *Cosmologia*, §§ 136-7.

[25] In §§ 153-4, Wolff explains that a change in speed modifies active force, and speed determines the "intrinsic state" of active force; in § 152, that speed is the "mode" of active force; and in § 164 that direction (of instantaneous motion) determines the "extrinsic state" of active force. He is explicit that a body's active force is in proportion to its mass in the earlier *Principia Dynamica*, a paper in vol. 1 of the St. Petersburg *Commentarii Academiae scientiarum imperialis* (1728), 222, § 20.

[26] Where 'm,' 's' and 'v' stand for mass, speed and velocity, respectively. I use boldface letters to denote vector quantities; e.g., '**v**' for velocity.

Newton's. In fact, Wolff is closer to Leibniz in conception: both call it a "force of resisting motion."[27] By that, Wolff means three things: (1) bodies resist self-acceleration; (2) a quiescent body resists the motion of an incoming; and (3) a slower moving body resists the motion of a faster one. In the last two cases, he has collisions in mind. Case (3) is a vexed situation in his dynamics.[28] But (2) is unproblematic, so it is natural to take Wolffian *vis inertiae* chiefly as a force *in bodies at rest*. Kant understands it thus. Then note how Wolff *differs* from Newton on this issue: for Wolff, a body in motion never *resists* one at rest, but *acts* on it; likewise, a faster one acts on a slower, never resists it. In contrast, in Newton's mechanics *both* bodies resist each other as they collide. Wolff's *vis inertiae* is less than Newton's inertia. Lastly, note that Wolff portrays his force of inertia as a "striving exerted against the striving of the acting body."

Another tenet in his doctrine is that mechanics, properly grounded, rests on a priori laws of motion. He makes this point as he discusses the "rules of motion," his phrase for a set of kinematic formulas, verbal or algebraic, relating initial and final speeds in the *collision* of bodies.[29] But these rules, he claims, are not mere generalizations from observed impacts, though some take them to be so. In fact, they can be derived from other, more secure statements he calls "laws of motion," whose proof is the privilege of philosophy:

> These days only a stranger to Mathematics is unaware that in the rules of motion there are general principles, from which these rules can be derived. These principles once established, the rules of motion, i.e. of impact, were proved from them in several ways. Mathematicians assume these laws without proof; but it behooves the Metaphysician to demonstrate them.

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[27] Wolff, *Cosmologia*, § 130. Leibniz describes his force of inertia thus: "We notice in matter a quality some have called *Natural Inertia* by which a body somehow resists motion, such that force must be employed to move it."—Leibniz, *Lettre sur la question, si l'essence du corps consiste dans l'étendue* (1691), GP IV 464.

[28] This is because the slower body moves too, so it has 'motive force' too, not just 'force of inertia.' Then it is unclear why, in the encounter with the faster body, the slower should exert its passive force of inertia rather than its active motive force, why it should resist rather than act. As Wolff spends no time untangling this knot, it is mysterious whether he is even aware of it. Next quotation: Wolff, *Cosmologia*, § 319.

[29] "The rules of motion are those according to which motive force is modified in the collision of bodies."—Wolff, *Cosmologia*, § 302. Next quotation: *ibidem*, § 303.

Wolff identifies two such a priori laws, the Principle of Inertia and a Principle of Action and Reaction.[30] He proves both, each in several steps. Crucially, his proof of the first law starts with his ontological *vis inertiae* as a premise, as Kant astutely notes. Wolff's second law of motion *sounds* like Newton's law of action and reaction, but it diverges from it significantly.[31] It rests on a view of interaction as an *asymmetric* encounter between agent and patient bodies, with action and reaction dynamically *heterogeneous*: action stems from the agent's *active* force, whereas reaction rests on the patient's *passive* force of inertia. Further, Wolff limits the range of his second law to *inelastic collisions*. Of course, neither his distinctions above nor the restriction to impact are compatible with Newton's theory, but they became a hallmark of Wolffian mechanics long after his *Cosmologia Generalis*. In its wake, a host of disciples go on to expound his philosophical mechanics, with no attention to its weaknesses.[32]

Though resolute that his two a priori laws of motion can and must ground a derivation of the rules of impact, Wolff is murky on the details of how the procedure might work. This is a sign that Wolff's law of action and reaction is not Newton's homonymous law; if it were, deriving rules of impact from it would be straightforward, as Wolff should know: the Newtonian MacLaurin had done just that, a mere few years before, in a 1724 prize essay competition.[33] But Wolff makes no mention of MacLaurin, nor does he adopt his derivation. Instead, he gives a merely verbal explanation of why two inelastic bodies in impact undergo equal changes of motion: one body is the agent endowed with 'moving force,' whereby it acts on the other, the patient which resists by its passive *vis*

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[30] Eric Watkins first drew attention to this unique feature of German rationalist dynamics, viz. their assumption of *just two* a priori laws of motion. Cf. his groundbreaking "The Laws of Motion from Newton to Kant," *Perspectives on Science* 5 (1997), 311–348. My argument in this paper owes a great deal to his insight there.

[31] I detail Wolff's proof of his Principle of Action and Reaction in section II.3 of my paper "Kant's third law of mechanics: the long shadow of Leibniz," forthcoming in *Studies in History and Philosophy of Science*, June 2011.

[32] Cf. J. H. Winckler, *Institutiones Philosophiae Wolfianae, Pars I* (Leipzig, 1735); J. Ch. Gottsched, *Erste Gründe der gesamten Weltweisheit* (Leipzig, 1735); J. Fr. Stiebritz, *Philosophiae Wolfianae Contractae Tomus I* (Halle, 1744); L. Ph. Thümmig, *Institutiones Philosophiae Wolfianae*, vol. I (Frankfurt, 1735); M. Ch. Hanov, *Philosophia Naturalis, sive Physica Dogmatica*, vol. 1 (Halle, 1762); N. Burkhäuser, *Institutiones Metaphysicae, Pars I: de Ente* (Würzburg, 1771).

[33] Cf. C. MacLaurin, *Démonstration des loix du choc des corps* (1724), reprinted in *Recueil des pieces qui ont remporté le prix de l'Académie royale des sciences*, vol. 1 (Paris, 1732).

inertiae. The agent spends as much 'force' as it needs to defeat the patient's 'force to resist.' With the residual 'moving force,' the agent drags along the patient, now unable to resist any more. This purely qualitative account leaves obscure how quantitative rules of collision might be derived from it. And, when he does try to derive rules, Wolff makes no mention of his law of action and reaction.[34] His disciples are just as opaque on how the rules supposedly follow from the laws; Kant is the first who makes a real effort to fulfill that promise.

Finally, Wolff's foundations of mechanics—his active and passive forces, agent and patient bodies, action and reaction, and laws of force—presuppose a concept of true motion, so as to be objective not arbitrary.[35] But one looks in vain for a clear account of that elusive concept in his work or even for a sign that he knows how hard and crucial it is. Wolff defines motion as "continual change of place," but fails to discern between true and apparent place or address Newton's duality absolute vs. relative place, though he rails against vacua and space metaphysically distinct from body.[36] He adds that to change place is to change "the order of coexisting," e.g. as the relative distance of four bodies A, B, C, D changes at different times; he then hints at an account of true motion, but equivocally. One is kinematic—A moves if B, C, and D keep the same

[34] He tries to derive rules in *Cosmologia*, §§ 386 sqq. But there he makes no use of action, reaction and their equality. Instead, he switches to a 'diffusionist' account of velocity exchange in collisions: upon contact between bodies A and B, the motion of the swifter diffuses itself throughout the 'enlarged body' AB temporarily formed by their contact. This allows Wolff to infer that, e.g., if A moving with a speed C strikes B at rest, post impact their joint speed V is equal to AC/(A+B). This is the 'rule of impact' for the particular case of collision with a body at rest.

[35] Briefly, here is why. (I ask the kind reader to allow me the vague notion 'frame of reference.') Take a body A at rest in some non-rotating frame **K**, where an observer *K* sees it. By Wolff's lights, A has only a passive *vis inertiae*, since it does not move, hence is devoid of active force; when a body B strikes it, A is the patient and B the agent; during their impact, B acts, A reacts. Now describe the same situation from a frame **L** (non-accelerated relative to **K**) where an observer *L* sees B at rest. In **L**, *L* sees A move; hence B counts as endowed with only passive force of inertia, whereas A has active, motive force; so, A is the agent and B the patient; A acts, B reacts. Clearly, what *kind* of force and dynamical *role* get ascribed to A and B varies with the choice of frame—because Wolff's concepts of force and action are *velocity*-dependent. Ergo, to render his concepts objectively valid, Wolff must single out a privileged frame of reference, with respect to which bodies have true velocities, not just relative or apparent ones.

[36] Chr. Wolff, *Philosophia prima, sive Ontologia*, editio nova (Frankfurt, 1736), § 642. His attack on the vacuum and absolute space is in § 599 and § 611. Next two quotes: *ibidem*, §§ 643-4.

distance relative to each other but not to A; Wolff's example is planets and comets moving relative to the fixed stars. The other is dynamical—A moves if A, B, C, D change relative distance but the "reason of the change" is in A; he explicates 'reason' as "the cause of the change," and illustrates it unhelpfully by a man pushing a ball A such that it alters distance to three balls B, C, D. These two accounts threaten to yield diverging *measures* of true motion, yet Wolff blithely ignores that danger and its implications.[37] True motion remains a lacuna in his foundational project. The young Kant will use this gap to pry his way into Wolffian mechanics and take it over.

IV- Kantian corrections

I have explained why Kant's arguments in *NL* disappoint if read as trying to adjust Newton's foundations of mechanics. But they become quite effective as remedies for problems in Wolff and his successors. With *NL*, Kant revises four vexed facets of Wolff's mechanics I described above: his (1) theory of motion; (2) a priori dynamical laws; (3) notion of *vis inertiae*; (4) grounding of impact in metaphysics.[38]

First, Kant sees that Wolff lacks a key ingredient, and steps in to produce it: a concept of true motion. In Wolffian mechanics, force is a velocity function: bodies in motion have *vis activa*, or *motrix*; resting ones

[37] Briefly, again, it is because the kinematic account entails that true motion means true *velocity*, whereas the dynamical only supports true motion understood as *acceleration*. If, when pressed on this tension, Wolff chose the second account to measure true motion, then true velocity is empirically not well defined in his mechanics, and this derails his typology of forces, velocity-dependent as they are.

[38] At this point, I should address a potential worry. One might require some proof that Kant had read (carefully) Wolff's *Cosmologia Generalis*, if the reader is to accept a construal that puts Kant in critical dialogue with Wolff. Though I have no direct evidence that Kant had read Wolff's *opus maius*, the evidence for my claim is overwhelming. *Cosmologia Generalis* was a best-seller in its time, with its second, 1736 edition quickly pirated at Verona and reprinted in Germany by Renger, the publisher of its first edition. In addition, I documented above how a host of lesser figures, from Gottsched to Hanov, expound the core of Wolff's metaphysical mechanics. I find it very implausible that Kant would have been unaware of this Wolffian school of thought on the foundations of mechanics. His preface to *Neuer Lehrbegriff* begins defensively by asking for understanding from "gentlemen who dismiss as chaff any ideas not ground at the mill of Wolff's celebrated theoretical system." This strongly suggests he has Wolffians in mind, at least in part, as he is about to embark on sketching a new theory of motion. I thank Oliver Thorndike for raising this point in private communication.

have *vis inertiae*. But to be objective, these dynamical traits need a theory of true motion to distinguish it from both *apparent* motion and true rest. Wolff relies on the "common concept" that motion is change of place, but fails to spell out what *true* place is, so as to ground *true* motion. Kant starts *NL* by pointing out this gap and how deficient its proposed solutions are. Then he offers his own fix—true motion as a *mutual relation* between interacting bodies. This relation has a kinematic side: speed; so two colliding bodies have true speeds "respective each other," inversely as their masses. Kant's doctrine of motion first makes it possible to say, within Wolffian mechanics, "with what speed and in what direction" colliding bodies move.[39] As a result, Kant is also in a position to determine the bodies' true amounts of *vis activa*.

Second, Kant continues Wolff's agenda of deriving laws of motion by a priori argument. Some of his premises are tacit, but only because he takes them for granted, just like his Wolffian audience: that moving bodies have "motive force," "actions" are effects of moving forces, and equal forces result in equal actions. For them, 'motive force' followed from ontological facts about bodies, and Kant gives no sign that he disagrees. Further, the Wolffians relied on the Principle of Sufficient Reason (PSR) to derive their laws, e.g. the equality of action and reaction.[40] Kant does too, so casually as to nearly evade our notice: having argued that true motion is a mutual relation, he adds that each interacting body has a share in it, and claims these shares are all equal, as we have "not the least cause" to assign a greater share to one over the other.[41] His is now a causal

[39] NL 2:17$_{15\text{-}17}$.

[40] Wolff proves his Reaction Principle in three steps: (i) in impact, for every action there exists a reaction; (ii) reaction is contrary to action; and (iii) a body acts upon another "with the same force as the latter has to resist it." He justifies steps (ii) and (iii) by arguing that "plainly, there is no reason why" [*nulla sane ratio est*] reaction should be in any other direction than contrary to action, or that the latter body should react more than the former acts. Cf. Wolff, *Cosmologia*, §§ 313, 316, 343.

[41] NL 2:18. Kant's original words are, "*ich nun nicht die geringste Ursache habe*," a common idiom in German. This might imply that I am reading too much into his phrase. But I am convinced he means to appeal to the Principle of Sufficient Reason. First, his argumentative move here is a close analogue of German rationalist inferences to the equality of two quantities – e.g., action and reaction – because allegedly *nulla sane ratio est*, "clearly, there is no reason why" they should be unequal. Second, Kant reprises this argumentative move in 1786, and *there* he says, "for there is no reason [*Grund*] to ascribe more motion to one than to another." We must remember that, for rationalists, the Principle of Sufficient Reason was eminently amenable to a causal reading: a *Grund* is an *Ursache*, or *causa*. I thank Oliver Thorndike for pressing me on this point.

version of the PSR; later he will make the same argument, but more explicitly: "for there is no reason to ascribe more motion to one than to another."[42] Recall Eric Watkins' discovery[43] that post-Leibnizian dynamics worked with *only two* laws of motion, and it is evident how Kant carries on their program: he rejects *their* law of inertia—understood as *a priori* and *based in ontology*—and replaces it with his first corollary; he keeps their law of action and reaction, but gives a new meaning to 'reaction.'

Third, Kant deposes the *passive* 'force of inertia' from Wolffian mechanics. He takes it to be primarily a force of rest, that 'force' whereby a quiescent body (1) resists self-motion, and (2) opposes a moving body trying to dislodge it. In Kant's new doctrine there is *no* true rest—*all* interacting bodies truly move, respective each other. So there is no need to posit in bodies a *vis inertiae* as "an inner force within them," or a "special force of matter," as he puts it later.[44] Thereby, Kant also severs the Wolffians' link between force of inertia and reaction. In consequence, he must now adjust the concept of reaction in their second law, of equal action and reaction. Recall that, in Wolff's mechanics, the two were dynamically heterogeneous: action results from active force, whereas reaction stems from passive force, the *vis inertiae*.[45] In Kant's corrected model, reaction is homogeneous with action: as bodies always *move* in impact, both are endowed with the *same kind* of power, 'moving force.' Hence action and reaction are dynamically on a par. Still, Kant *retains* the Wolffians' notion of 'moving force' as the agency a moving body has simply because it moves. And he *keeps* their view that the law of action and reaction is a priori. For these reasons, we must count him as an internal reviewer of Wolff's project, not an external critic.

Fourth, Kant makes good on the Wolffians' pledge to explain how kinematic rules of impact rest on a priori laws of motion, thus showing that empirical mechanics needs philosophy. Kant's first law picks out the true motions of bodies *before* impact, and his theory of motion quantifies them; his second law then predicts their true motions *after* collision: relative rest. Add to this a priori dynamics the equally a priori geometry of velocity transformations across 'relative spaces,' and a full set of kinematic rules of collision ensues. Though Kant infers just two such rules, he offers elements for a complete solution, provided the impact is direct. Thereby, he inherits the post-Leibnizian agenda of grounding

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[42] MAN, 4:545 (Proof).

[43] Watkins, "Laws of Motion," 316-23.

[44] NL 2:20f.; MAN 4:549 (Remark I).

[45] Wolff is explicit about that: "The body reacts by its force of inertia."—*Cosmologia*, § 316.

impact in philosophy, but supplants the Wolffians' qualitative account with an exact quantitative derivation.

V- Precedent and aftermath

Thus by 1758 Kant has the gist of an a priori impact mechanics, developed by constructive dialogue with Wolff and his followers, and based on forces and dynamical laws distinct from the 'Newtonian' physical astronomy and theory of matter he had outlined in 1755-6. Kant's *NL* weaves in certain strands from his early dynamics, and announces insights seminal for his later natural philosophy. To see these continuities, a closer look at *NL*'s central themes is instructive.

Force of motion. In the youthful *New Estimation of Living Forces*, Kant had cast himself as mediator in the strife between 'Cartesians' and 'Leibnizians' on the vexed issue of a 'force of motion' in bodies. Both parties agreed on one premise, as does Kant: "that a body which is in motion has a force."[46] The quarrel was over the 'true' measure of this 'force': followers of Descartes and Malebranche thought it equal to $m\boldsymbol{v}$ (in our terms, the body's linear momentum), whereas the Leibnizian party championed mv^2, or twice its kinetic energy; their term of art for the 'force of motion' was *vis viva*, 'live force.' Already in 1747, Kant seeks to distance himself from the Leibnizians in important respects. First, he wants to restrict the range of their preferred *vis viva*. Second, he makes friendly overtures toward the Cartesians: he says that $m\boldsymbol{v}$ is the *only* sound measure in mathematical investigations of the moving forces that bodies *exert on each other*.[47] In fact, he shores up their side with a "new case that confirms the Cartesian measure of force," $m\boldsymbol{v}$: he starts with two bodies A and B balanced on a scale, and argues that consecutively adding two small bodies *e* and *d* will induce in A and B virtual velocities inversely proportional to the masses of *e* and *d*. He deduces, "hence two bodies with velocities inversely as their masses have equal forces." Ergo, he means 'force' in interactions to be measured by $m\boldsymbol{v}$, along 'Cartesian' lines.

Bear this result in mind, and we find Kant adopt the same line in *NL*.

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[46] LK § 1; AA 1:17. Note how alien this presumption is to Newton's own foundations of mechanics: according to the *Principia*, the 'force' of bodies in uniform motion is *the same* force they have at rest: the *vis insita*, or *vis inertiae*; and it is equal to the body's *mass*, not to any of the two measures that divided Leibnizians and Cartesians. Moreover, properly Newtonian force is *vis impressa*, equal to the change in momentum in a given time induced in the body acted upon. Neither side in the *vis viva* controversy captures this insight.

[47] LK § 28, 1:41. Next quote: *ibidem*, § 109, 1:121f.

Having argued that two colliding bodies have true motions 'respective each other,' he takes their true velocities to be inversely as their masses. Ergo, their individual quantities ***mv*** will be equal. He concludes: "and it is really with these forces [*Kräfte*] that the two bodies will act on each other in impact."[48] Again, as he applies his concept of relative motion to a cannonball hitting a wall: "both are in motion toward each other, … the one with the same *force* as the other." And again, as he explains that two bodies approach mutually with equal momenta in impact: "and it is with these equal *forces* that they will collide." Then twice again, as he predicts, from his theory of motion, the outcome of his test-case of impact: "because of the equality of *their contrary forces* the bodies come to relative rest." Evidently, he assumes that, by moving, each body has a 'force' whereby it acts on the other, and that ***mv*** measures this force, just as he had claimed in his 1747 'Cartesian' move contra the Leibnizians.

This motif endures, showing how keen he is to retain early insights. In the Critical years, seeking again to ground mechanics in metaphysics, he claims that the concept of matter underlying mechanics is, "matter is the movable to the extent that, as mobile, it has moving force."[49] That is, mechanics begins by assuming that a body *in motion* has moving *force*, or the capacity for "communicating [its] motion to another [body]." This idea is the backdrop to Kant's analysis of impact, a part of his account of action and reaction. Just as in 1758, he makes the point that two colliding bodies have true motions "equal and opposite to one another." On the surface, he writes as if to say the bodies' two opposite motions cancel each other out *directly*, so rest ensues.[50] But that is not really his view.[51] Rather, he sees

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[48] NL 2:18. Next three quotes: *ibidem*, 2:19, 20, 25 (emphasis added).

[49] MAN 4:536.

[50] This is, in fact, how some have read Kant's account of impact in *MAN*'s *Mechanics* chapter. See, e.g., H. Duncan, who alleges that Kant there offers a "purely kinematical" analysis of impact, in his "Inertia, the communication of motion, and Kant's third law of mechanics," *Philosophy of Science* (1984), 93-119. On my reading, Kant's account of impact is thoroughly force-driven: it involves *both* kinds of forces – mechanical and 'dynamical' – in his philosophy of physics.

[51] That is for three reasons: if it were, it would make his notion of moving force entirely idle; it ignores his early philosophical mechanics; and it would condemn him to transfusionism, the very sin he pillories in others. The latter is because, if Kant really tried to analyze "communication of motion" in impact purely kinematically, he would have to assume that one body transmits its whole motion to the other (as mutual rest is the outcome of their collision, in Kant's analysis). But transmission of motion is the core idea in transfusionism, the view that in impact motion "were poured from one body into another like water." This, charges Kant, violates the metaphysical tenet that accidents do not migrate from one

the two bodies as moving equally, hence endowed with *equal* amounts of *mechanical force*; since their forces are equal, they *balance* each other in impact, producing mutual rest. Kant's Critical mechanics of impact inherits his early one in *NL*; both rest on *his* idea of moving force—and the product ***mv*** as its measure—adumbrated as early as 1747.

Relationism. To ground his revised Wolffian mechanics, the young Kant outlines a theory of true motion: an idiosyncratic form of relationism. Like Descartes, Newton, Berkeley (and perhaps Leibniz), Kant accepts that bodies have true motions, not just apparent ones. Unlike them, however (though rather like Huygens), Kant insists that true motion is not a predicate of single bodies, but an *irreducible relation* between bodies that interact. Still, he adds, each relatum, or body, has a true share in this relation, which is its true motion respective the other body; and these shares are equal. The quantity of each share is the body's linear momentum with respect to the center-of-mass of the collision. The paradigm of Kantian true motion is the inelastic impact of two bodies.

The same train of thought resurfaces in 1786. In his *Mechanics*, to prove that in the "communication of motion" action equals reaction, Kant alleges first that motion is an "*active* relation of matters *in space*," and infers that this relation is the *mutual* motion of bodies as they interact, e.g. in a collision; that they "must have an equal share" in their mutual relation; and that each share is the body' momentum in a "relative space" in which the system' center-of-mass rests.[52] Then Kant continues this thought in *Phenomenology*, where he makes it a theorem that whenever a body moves relative to another, the latter also moves relative to the former —with an equal and opposite motion. This is necessary, he claims, because it follows by mere analysis from a concept—that of "the relation of the *moved* to anything *movable* by it in space."[53] A pithy though

substance to another. Cf. MAN 4:550. Duncan alleges, "one may lay a similar charge against Kant's explanation if it is to be interpreted kinematically."—Duncan, "Inertia," 108. But, of course, the charge only applies if Kant indeed analyzes impact in purely kinematic terms. As I showed above, that it false.

[52] MAN 4:545f (emphasis in the text). Kant calls that "absolute space," but in the sense of his *Phoronomy*, i.e. that of "any other relative space that I can always think beyond a given [relative] space, and which I can extend to infinity beyond any given space, as a space that includes the latter and inside which I can assume the latter to be moved."—*ibidem*, 481. In Kant's analysis of impact in *Mechanics*, the given relative space is the finite volume in which an observer sees B, one of the two bodies, initially at rest. The 'absolute space' denotes another, arbitrarily large volume, in which the center-of-mass of A and B is at rest—hence in which the initial observer and her 'relative space' count as in motion.

[53] MAN 4:558.

recognizable paraphrase, to be sure, of Kant's 1758 idea that true motion is a privileged relation between bodies that affect each other mechanically through their motion, the initial thought of his *NL*. Unmistakable is also his exclusive focus on inelastic impact, nearly three decades after *NL*'s philosophical mechanics of collision.

A priori laws. From Wolff and his disciples, the young Kant inherits the task of proving laws of motion a priori. By deductive reasoning from premises about the nature of motion and the measure of 'force,' he proves Law 1, that in collisions all bodies truly move (relative to one another); and Law 2, that in impact action equals reaction; and he demotes the Law of Inertia to a mere empirical regularity, not provable from philosophy.

Prima facie, the Critical foundations of mechanics depart from this early view significantly. But scratch the surface, and continuities emerge. In *MAN*, Kant has three "mechanical laws," yet only two are laws of *motion*.[54] Of these, first is the Law of Inertia, now derived a priori; the second is *his* Law of Action and Reaction.[55] To them, he appends a "law of nature not unimportant for general mechanics": that any body in impact is movable by any other body, because both are truly in motion. This is visibly his old 'first corollary,' Law 1 of the 1758 *NL*. Note also that Kant is confident he can *prove* his laws a priori, just as the Wolffian agenda required and as he had done already in *NL*. Remarkably, just as it did in 1758, his Critical proof for the two laws—of equal action and reaction, and the 'law of movability' in impact—rests on (1) his account of motion as mutual relation between interacting bodies, and (2) his concept of mechanical 'moving force' and its measure. Not least, a telling lacuna: Newton's *Second* Law—the keystone of 'Newtonian' mechanics—never appears as an official law of *Kant*'s mechanics, early or late. Of course, it is because Kant's philosophical mechanics, as I have argued, is a variant of Wolff's analogous theory, which also lacked Newton's *Lex Secunda*.

Grounding impact. The juncture of Wolff's a priori mechanics and empirical science was the kinematics of collision: allegedly, the 'rules of impact' presuppose 'philosophical' laws of motion, which he then produced. The young Kant is heir to that program, though an unruly one. That is just as well, for the master's execution had flaws. He corrects Wolff's mistakes, and shows in *NL* that his laws yield the rules, as Wolff

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54 The first is a global principle of conservation of mass; it implies nothing about the motion of bodies, whether free or interacting by means of forces.

55 I call it 'Kant's Law of Action and Reaction' because it is not the same as or empirically equivalent to Newton's homonymous *Lex Tertia*. Some have already recognized this; cf. Duncan, "Inertia," 102f., 107. Next quote: MAN 4:548. Details on how they differ are in Stan, "Kant's third law."

wanted.

He carries on the project into the 1780s, now with more finesse. In *MAN*, he tasks mechanics with "constructing the communication of motion," i.e. quantifying *velocity exchanges in impact*.'[56] He clarifies that agenda with an example, constructing the communication of motion in impact with a body at rest. Kant claims that the geometric construction of collisions "carries with it as its necessary condition" his law of action and reaction, which he proves in *Mechanics*. In fact, other conditions are just as necessary for his mature mechanics of impact: the a priori, geometric kinematics of composite motion grounded in *Phoronomy*, and his idea of motion as a mutual relation, further expounded in *Phenomenology*. But these Critical additions should not obscure the gist of his enterprise: "constructing the communication of motion" is Kant's term for a geometric representation of the 'rules of impact,' which he derives from his theory of motion and a priori laws—just as he did in 1758 and as Wolff had required.

To be sure, we must not ignore some watershed changes in Kant's natural philosophy as he adopted transcendental idealism.[57] But, it seems to me, not enough has been made of these striking continuities between his early philosophy of mechanics and its mature version.

VI- Conclusion

Though widely thought to have become a Newtonian after 1755, Kant stays, even after his conversion, in thrall to a post-Leibnizian philosophy of mechanics, which he updates in novel ways. This philosophy, heavily

[56] MAN 4:549.

[57] To be sure, the deepest change comes from the very move to critical idealism. For the pre-Critical Kant, corporeal forces and true motions are objective in the sense of transcendental realism—they belong to bodies as things-in-themselves. After 1781, Kant cannot afford to defend that line any longer. In his *Phenomenology*, he makes clear that he distances himself from the common assumption of all early modern theories of motion (except Huygens's), according to which bodies have true motions *beyond or 'behind' their apparent* ones. Armed with the insight that the epistemic subject partially constitutes knowledge, or experience, Kant now explains that, in a Critical theory of motion, "we must indicate the conditions under which the object (the matter) must be determined in one way or another through the predicate of motion. This is not an issue of transforming illusion [*Schein*] into truth, but of turning appearance into experience" (4: 555). To be sure, a good deal more deserves to be said on this point, though not within the limited confines of this paper. I thank Oliver Thorndike for raising this important point.

influenced by Wolff, remains in Kant's thought the core of an a priori mechanics that he continues to articulate as late as the *Metaphysical Foundations of Natural Science*. His unique contribution to the Wolffian agenda is a theory of true motion that, incidentally, aligns Kant with major relationists such as Descartes, Huygens, Leibniz and Berkeley. It also puts him at odds with Newton's absolutism, though his first outline of a theory of motion is not meant to engage with or supplant Newton's views but to fill a gap in Wolff's doctrine.[58]

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