
The Metaphysical Roots of Cartesian Physics: The Law of Rectilinear Motion

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This paper presents a detailed account of Descartes' derivation of his second law of nature—the law of rectilinear motion—from a priori metaphysical principles. Unlike the other laws the proof of the second depends essentially on a metaphysical assumption about the temporal immediacy of God's operation. Recent commentators (e.g., Des Chene and Garber) have not adequately explained the precise role of this assumption in the proof and Descartes' reasoning has continued to seem somewhat arbitrary as a result. My account better reveals the dependence of the second law on fundamental principles about time and causality.

1. Introduction.

In his preface to the French edition of the *Principles of Philosophy*, Descartes says that all philosophers (even Aristotle) have recognized that the surest and most elevated path to wisdom “consists in the search for the first causes and the true principles which enable us to deduce the reasons for everything we are capable of knowing” (AT 9B 5; CSM 1 181).¹ What distinguishes his own system, Descartes tells us, from those of other philosophers is that his is founded upon principles that are absolutely clear and indubitable, such as the existence and nature of ourselves and God. Not that the other philosophers seriously doubted such principles. Rather, “there has been no one up until now who has recognized them as the ‘Principles of Philosophy’, that is as the principles which enable us to de-

Thanks to Roger Ariew, David Brokken, Mary Domski, Tom Lennon, Tad Schmaltz, Ed Slowik and Kurt Smith for comments on earlier versions of this paper.

1. In what follows ‘AT’ refers to Descartes (1996), ‘CSM’ refers to Descartes (1985), ‘CSMK’ refers to Descartes (1991), ‘MM’ refers to Descartes (1983), ‘WO’ refers to Descartes (1998), ‘CB’ refers to Descartes (1976), and ‘O’ refers to Descartes (1965).

duce the knowledge of all the other things to be found in the world” (AT 9B 10–11; CSM 1 184). So, in Descartes’ mind, the unique virtue of his natural philosophy is the certainty it inherits through derivation from the self-evident principles of metaphysics.

Since God is the first, complete and continuing efficient cause of all there is or can be, “it is very clear that the best path to follow when we philosophize will be to start from the knowledge of God himself, and try to deduce an explanation of the things created by him” (AT 8A 14; CSM 1 201).² For instance, the “secondary and particular” causes of motions (the laws of nature) must be derived from the principles of divine creation, since God is the “first and universal cause” of motion (AT 8A 61–2; CSM 1 240). Considered in this light, Descartes’ second law of nature—the law of rectilinear motion—presents special challenges for students of his physics. Like the other two laws it is ostensibly grounded on the immutability of God’s creative operation: “God alone is the author of all the motions in the world insofar as they exist and insofar as they are straight” (AT 11 46; CSM 1 97). But unlike the other laws the proof of the second law seems to depend essentially on a metaphysical assumption about the temporal immediacy of God’s operation. According to Descartes, it is somehow because God only conserves motion in the precise form in which it is occurring “at the very moment when he preserves it” and without “taking account” of earlier motions, that his immutability constrains him to produce only rectilinear motion (AT 8A 64; CSM 1 242). The precise role of this assumption in Descartes’ proof of the second law has not been adequately analyzed by recent commentators. Indeed, as I will attempt to show through examination of two prominent interpretations (Dennis Des Chene and Daniel Garber), Descartes’ reasoning looks rather weak and arbitrary if the significance of the temporal premise is not sufficiently appreciated.³ In the concluding section of the paper, I will offer my own account which I think better reveals the metaphysical foundation of the second law and so, at least on this point, the unity of Descartes’ metaphys-

2. Similar methodological strictures are presented in the earlier *Discourse on the Method* (AT 6 64–5; CSM 1 143–4) and *le Monde* (AT 11 43–4; CSM 1 95–6). In the latter work, he goes so far as to say he would accept the laws of nature as derived from God’s immutability “even if everything our senses experienced in the real world seemed manifestly contrary” to the laws: “For what more firm and solid foundation could one find for establishing a truth, even if one wished to choose it at will, than the very firmness and immutability that is in God?” (AT 11 43; CSM 1 95–6). I do not here consider what sort of necessity (logical, metaphysical, physical) is supposed to be conferred upon the laws of nature via their deductive dependence on metaphysics. For discussion of this question, see Clarke (1982, Ch. 4), Broughton (1987), and Nadler (1990).

3. Others, such as Williams (1978, p. 269) and Nadler (1990, p. 366), despair of finding an interpretation that makes the argument anything more than merely suggestive.

ics and natural philosophy. But first I must explain precisely what the second law requires.

2. The Proof of Rectilinear Motion

Descartes' second law of nature (third in *le Monde*) states "all motion is in itself rectilinear" (AT 8A 63; CSM 1 241). Of course, as Descartes mentions when he introduces the law, the actual motions of bodies in the plenum are always circular, or at least 'loopy': "in any motion, the result of all the matter moving simultaneously is a kind of circle" (AT 8A 63; CSM 1 242).⁴ But he insists that although all the parts of a body may move in a circle, "the action (*action*) of these parts—i.e., the inclination (*inclination*) they have to move—is different from their motion" (AT 11 44; CSM 1 96).⁵ So, what the law more precisely demands is that bodies in motion will have at all times a rectilinear "tendency" (or *inclination* or *action*). Unlike actual motion, tendency is an instantaneous state of bodies which may or may not give rise to actual motion over time: "Note that I am not saying that rectilinear motion can take place in an instant, but only that all that is required to produce it is present in each instant (*en chaque instant*) that may be determined while they are moving" (AT 11 45; CSM 1 97). Even processes which involve no motion at all can manifest a real tendency to motion. For example, the outward rectilinear force of light particles from the sun "does not consist in any duration of motion, but only in the pressing or first preparation for motion (*in prima preparatione ad motum*), even though actual motion may not result from this pressure" (AT 8A 115). Though Descartes sometimes characterizes this tendency as a "striving" (*conatus*) (AT 8A 108; CSM 1 259), this is emphatically not intended to indicate any sort of volition on the part of the body. Rather, the tendency a body has is simply its disposition to move in a certain way under certain circumstances. Thus, he explains in *le Monde*: "When I say that a body tends in some direction, I do not want anyone to imagine that there is a thought or will (*une pensée ou une volonté*) in the body that bears it there; only that it is disposed (*est disposé*) to move there whether it actually moves or whether some other body prevents it from doing so" (AT 11 84; W0 54).⁶

4. See *Principles* II, 33 (AT 8A 58–9; CSM 1 237–8).

5. See also his account of the distinction in the *Optics* (AT 6 88; CSM 1 155).

6. See also *Principles* III, 56: "When I say that the globules of the second element 'strive' (*conari*) to move away from the centers around which they revolve, it should not be thought that I am implying that they have some thought from which this striving proceeds. I mean merely that they are positioned and pushed into motion in such a way that they will in fact travel in that direction, unless they are prevented by some other cause" (AT 8A 108; CSM 1 259). In correspondence with Mersenne, he uses scholastic terminology: tendency is the

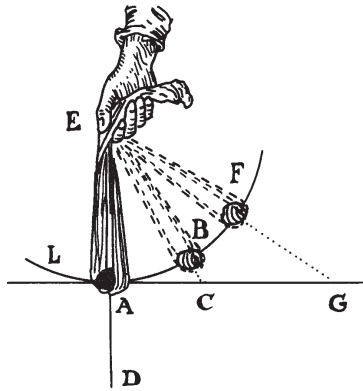


Figure 1.

Bodies can have any number of tendencies at a given time, depending on their interaction with other bodies.⁷ The combination of all these tendencies, which we might call the body's *cumulative* or *overall tendency*, determines its actual motion. For example, Descartes says that a stone swinging in a sling (see Figure 1) “definitely tends” to follow a circular path from A to B “if all the combined causes which determine its movement from A to B are considered simultaneously, because it is in fact thus transported” (AT 8A 108; MM 112).

So for any given body its overall tendency is simply to move in the way it actually does move. Descartes even indicates that a body can have an overall tendency to *rest* if its tendencies to move in various directions all offset one another. In a letter to Morin, he gives the example of two blind men who alternately push, and then pull, opposite ends of a stick: “what each man feels in the stick, namely a lack of movement in various respects, can be called the various actions which are impressed on it by the various exertions of the other man” (AT 2 363; CSMK 120–1).⁸ But along with its

“potentiality” and motion is the “actuality.” And he points out that something can be in some state potentially though never actually, but not vice-versa (AT 1 451; CSMK 74).

7. Individual tendencies also have (or can be imagined to have) parts. Thus, Descartes says we can “imagine this stone’s inclination to move from A to C [See Figure 1] as if it were composed of two other inclinations, one turning along the circle AB and the other rising straight up along the line VXY” (AT 11 85; WO 54–5). See also *Principles III*, 57 (AT 8A 108–9; MM 112). For a good discussion of the “component” nature of tendencies and determinations, see McLaughlin (2000, pp. 87–97).

8. The parts of the earth are in such a state of “tendency equilibrium” according to Des-

overall tendency we can also consider the tendency that every moving body possesses independently of all other bodies, which we might call its *proper tendency*.⁹ This is the disposition the body has to move a certain way if it is isolated from the influence of all other bodies.¹⁰ In the case of the stone in the sling (Figure 1), Descartes says this tendency is always to move along the tangent of its circular path: “the same stone tends toward C when it is at point A if we consider only its own force of movement (and agitation), assuming AC to be the straight line which is tangent to the circle at A” (AT 8A 108–9; MM 112).¹¹ Thus, Descartes frequently speaks of

cartes. (See Chapter 11 of *le Monde*: AT 11 75–7). See also *Optics*, First Discourse (AT 6 87–8; CSM 1 155–6).

9. Not to be confused with Descartes’ distinction in *Principles* II, 31 between the “proper” and “shared” motion of a body. The former is the transfer of a body relative to contiguous bodies (AT 8A 57; MM 53–4). The latter is the transfer of the bodies of which it is a part, relative to their contiguous bodies. Thus, the wheels of a sailor’s watch have only a proper circular motion considered relative to its casing, but various complex shared motions considered relative to the sailor, the ship, the sea, and so on.

10. According to Descartes, bodies at rest can also have a proper tendency to rest, which is as real as the tendency to certain kinds of motion. But that is another matter. For discussion, see Garber (1992, pp. 278–80).

11. Some commentators have worried that Descartes’ apparent attribution of circular tendency to the stone earlier in this passage is inconsistent with the second law, and possibly even an indication that Descartes “had returned unconsciously to embrace the idea of a natural circular motion” (Westfall 1971, p. 82). But there is no inconsistency if we hold to the distinction between overall and proper tendencies. The stone has an overall tendency to move in a circle (“if all the combined causes are considered simultaneously”) and a proper tendency to move along the tangent (“if we consider only the force of its own movement and agitation”). For recent discussion see Gaukroger (2002, pp. 116–21) and Slowik (2002, pp. 62–71). Slowik suggests that there is stronger evidence for Cartesian circular inertia in a 1638 letter to Ciermans. In that letter, Descartes implies that there is no reason why the particles of light should not “maintain the rotational motion that gives rise to colors as much as the straight line motion of which light consists” (AT 2 74). Based on this remark, Slowik suggests “celestial particles retain rotational motion in the same manner that they retain straight-line motion, the latter being subsumed under his second law of nature” (2002, p. 70). But the issue with Ciermans seems to be the *persistence* of motion, not its *direction*. And even if it is as natural for rotational motion to persist as straight motion, it does not follow that the former is “as inertial” as the latter. For it may turn out that the plenum favors the persistence of non-inertial motions over inertial ones. The question then is whether the persistence of rotational motion owes itself to a proper, as opposed to an overall, tendency. Descartes invokes the rotation of light particles in the *Optics* and the *Meteorology* to explain the color spectrum. In the *Optics*, he says that straight motion is “simple and ordinary” while rotational motion is “acquired” when light is reflected, which suggests that only straight motion is proper while rotational motion is derived (AT 6 89–90; O 71). Likewise, in the *Meteorology*, to which he refers Ciermans, Descartes says that the particles “can roll in various ways according to the various causes which determine them” (AT 6 331, O 336). He goes on to tell an elaborate story about how different particles roll at greater or lesser speeds depending on the rolling of the particles that surround them.

the tendency of the parts of bodies to move in a straight line as something they possess “taken individually” (AT 11 44: CSM 1 96)¹² or “considered in isolation” (AT 11 84; W 54)¹³ Finally, one must distinguish between the tendency of moving bodies and their “determination.” As Daniel Garber explains, tendency is an instantaneous feature of bodies while determination is “a directional component of the motion a body has” (Garber 1992, p. 220). But, as Garber also points out, we can speak of tendencies as having determinations also, which would be the instantaneous tendency a body has to move in a certain direction were it moving and were it isolated from other bodies.¹⁴ So we can now see that in holding that “all motion is in itself rectilinear” what the second law of nature more precisely postulates is that the determination of the proper tendency of each part of a moving body is always along a straight line.¹⁵

Let us turn now to the proof of the law, which in the *Principles of Philosophy* (Part II, Section 39) is as follows:

The reason for this second rule is the same as the reason for the first rule, namely the immutability and simplicity [*immutabilitas et simplicitas*] of the operation by which God conserves motion in matter. For he always conserves the motion in the precise form in which it is occurring at the very moment when he preserves it [*eo ipso temporis momento quo conservat*], without taking account of the motion which was occurring a little while earlier [*nulla habita ratione ejus qui forte fuit paulo ante*]. It is true that no motion takes

What this suggests is that when he speaks in the *Meteorology* of particles having a “tendency to rotate” (AT 6 333; O 337) he is referring strictly to what I have called their overall tendency, i.e., their actual motion that results from interaction with other bodies in the plenum. It needn’t be their proper or inertial tendency, i.e., their tendency to move a certain way were they the only body in the universe. Accordingly, when Descartes says in the Ciermans letter that there is no reason why rotational motion should not persist, he may mean simply that there is no reason why the total quantity of motion in the plenum should be distributed differently than it is, rather than that rotational motion is privileged.

12. See also AT 8A 63; CSM 1 241.

13. See also *Principles* III, 56: “I mean merely [concerning the rectilinear striving of bodies] that they are positioned and pushed into motion in such a way that they will in fact travel in that direction, unless they are prevented by some other cause” (AT 8A 108; CSM 1 259).

14. An insightful discussion of Descartes’ notion of tendency is given by Della Rocca (1999, esp. pp. 54–8). For detailed analysis of the notion of determination in Descartes’ physics, see Gabbey (1980, Part II) and McLaughlin (2000).

15. “According to this rule, then, we must say that God alone is the author of all the motions in the world in so far as they exist and in so far as they are straight, but that it is the various dispositions of matter which render the motions irregular and curved” (AT 11 46; CSM 1 96).

place in a single instant of time; but clearly whatever is in motion is determined [*determinatum*], at the individual instants which can be specified as long as the motion lasts, to continue moving in a given direction along a straight line, and never in a curve [*continuum versus aliquem partem, secundum lineam rectam, non autem unquam secundum ullam lineam curvam*] (AT 8A 63–4; CSM I 242).

He proceeds to illustrate the law by the example of a stone in a sling, which I have already mentioned (see Figure 1). Although the motion of the stone is in fact always along the circular path ABE, at any point A “it is inclined to move along the tangent of the circle from A towards C” (AT 8A 64; MM 61). Not only do we find it “impossible to imagine” that its tendency at that point should be curved, its rectilinear tendency is also confirmed by experience, such as the straight motion we observe if we release it and the “pull” we feel on the sling if we don’t. (Ibid.)

The proof is puzzling in a number of ways. Descartes’ point cannot be that it is impossible to imagine bodies having *cumulative* non-rectilinear tendencies since, as we have just noted, bodies always do have such tendencies. Rather his claim is that the *proper* tendency of all moving bodies will be rectilinear owing to the immutable nature of God’s operation. In particular, God conserves motion only in the instantaneous form it has without “taking account” of any earlier or later motions. But it is not at all clear why God cannot take account of what is earlier and later, even while immutably conserving motion, just as a painter might take account of the parts of a line she has already drawn, and those she is about to draw, without veering from her plan. Nor is it clear why such single-mindedness on God’s part should constrain him to give only a rectilinear tendency to bodies. Given we are dealing with an instantaneous mode, why can’t God always conserve a “curvilinear tendency” in all parts of bodies, such as the tendency to move in a circle? Perhaps the very idea of a proper curvilinear tendency is problematic. But if so, why should this depend on either the immutability of God’s operation or the relation of that operation to time? In the hope of finding answers to these questions, I will next examine two recent reconstructions of the proof.¹⁶

16. One obvious place to look for clarification is the natural philosophy textbooks of Descartes’ followers. Unfortunately, these texts offer proofs that are even more condensed than Descartes’. Rohault says simply that rectilinear determination is natural because everything endeavors to continue in the same state and only rectilinear determination is “natural to a body in motion” (Rohault [1723] 1969, Bk. I, Ch. 15). Similarly, Régis says that the second law follows from the “metaphysical axiom” that any change in an object results from an exterior cause: “for the same reason a body determined to move in a certain direction will continue to be determined to move in that direction if nothing impedes it”

3. Recent Reconstructions: Des Chene and Garber

Dennis Des Chene presents an historically detailed reading of the proof in his recent *Physiologia: Natural Philosophy in Late Aristotelian and Cartesian Thought* (Des Chene, 1996). Des Chene points out that it is unlikely Descartes would have thought it *self-evident* that the tendency of moving bodies must be rectilinear. Neither Galileo, nor Descartes' own teacher Isaac Beeckman, considered circular motion to be inherently less natural than straight motion (1996, p. 283). Hence the need for a solid proof. According to Des Chene's account, the crucial assumption is the *simplicity* of God's operation, which is emphasized by Descartes especially in the following *le Monde* version of the proof:

God conserves each thing by an uninterrupted action, and consequently he conserves it not as it might have been at some earlier time but precisely as it is at the very instant he conserves it. So, of all motions, only motion in a straight line is entirely simple and has a nature which may be wholly grasped in an instant. For in order to conceive of such motion it is sufficient to think that a body is in the process of moving in a certain direction, and that this is the case during each determinable instant during the time it is moving. By contrast, in order to conceive of circular motion, or any other possible motion, it is necessary to consider two of its instants, or rather two of its parts, and the relation between them (AT 11 45; CSM 1 96–7).

As Des Chene understands him, Descartes' point is that the specification of motion along a straight line can be given by a single direction (e.g., "go due east"), whereas the specification of curved motions requires more directions (e.g., "go southeast, then due east, then northeast").¹⁷ "It is in this sense," says Des Chene "that only the straight line is 'entirely simple'" (1996, p. 284).¹⁸ He goes on to observe that Descartes' conception of simplicity as unidirectionality is reminiscent of the Aristotelian association between simplicity and unity, and concludes that "Descartes' requirement

(Régis [1690] 1970, Vol. I, Bk. 3, Ch. 14). In both cases, these Cartesians simply assume that the instantaneous determination of a body will be rectilinear and will persist naturally, and leave it to the master to provide a justification for this assumption.

17. Not surprisingly, simplicity is the basis for Malebranche's defense of rectilinear motion: "As only rectilinear motion is simple, it must be considered as the one with which all bodies tend to move, since God always acts in the simplest ways" (Malebranche 1980, p. 456).

18. Similar, though much less detailed, accounts are offered by Blackwell (1966, pp. 223–4), Westfall (1972, p. 59), Machamer (1976, pp. 189–90), Clarke (1982, p. 94), and Nadler (1990, p. 369).

of simplicity—a simple motion is that which has one direction—appears to be a transposition into his physics of the Aristotelian criterion of unity” (1996, p. 285).

Des Chene’s interpretation of the *le Monde* version of the proof is illuminating and clearly right—as far as it goes. Descartes does rely on simplicity considerations, and he does seem to assume that the simplest motion, or the simplest tendency to motion, is the one that can be specified by a single direction.¹⁹ The problem is that if this is all there is to the argument, then it seems quite weak. For, to begin with, *a priori* criteria of simplicity are notoriously difficult to justify. Thus, although straight motion is perhaps the simplest in directional terms, circular motion is simpler in having identical beginning (*terminus a quo*) and end (*terminus ad quem*) points, as Des Chene himself points out (1996, p. 285). Even if we stick to the directional criterion, judgments of comparative simplicity will vary with different conceptions of “direction.” Des Chene defines the direction between two points as the straight line that runs through them,²⁰ from which it follows immediately that straight motions are the simplest directionally. But other definitions would generate different rankings. If we defined the direction between two points as the arc of the circle that has as its diameter the straight line connecting them, then the circular path would be the simplest. One might insist that the former definition better captures our intuitive notion of directionality. But even this is not obvious. For example, if I travel due east from Quebec City I will eventually reach the shores of the Caspian Sea, but I will have followed a curved along the surface of the globe not a straight one.²¹ Although this argument might seem fanciful, it is not historically unfounded. Indeed, according to Stephen Menn, this is precisely how Aristotelian defenders of circular motion, such as Avicenna, would have responded to Descartes’ proof: “Avicenna would say that the conservation of circular motion satisfies this condition [directional simplicity]: the sun’s mover always gives the sun an

19. In *Principles* II, 32 Descartes says that the straight line is the “simplest of all” lines, even though we can imagine it “as arising from an infinite number of different motions” (AT 8A 58; CSM 1 237).

20. “By ‘direction’ I mean the relation between point *A* and any other point *B* on a straight line through that point” (Des Chene 1996, p. 283). One might want to revise this slightly in order to capture the asymmetry of direction: the direction from New York to London is not the same as the direction from London to New York though the cities are related by the same straight line.

21. It is an interesting and difficult question what sort of meaning the notion of direction has in “Cartesian spacetime,” which seems to lack any privileged reference frame. For a stimulating discussion of Descartes’ relationist conception of space, and its implications for his laws of motion, see Slowik (2002, especially Chs. 3 and 6). See also Garber (1992, pp. 162–72) and Des Chene (1996, pp. 255–72).

inclination to move westward around the earth, without referring to the sun's previous history" (Menn 1990, p. 232). So the inference from directional simplicity to rectilinear motion can hardly have the status of "absolute clarity" which Descartes demanded of the true "Principles of Philosophy."

In any case, we need to keep in mind that it is the simplicity of *God's operation*, rather than the resulting motion, which is supposed to ground the second law: "God conserves each thing by an uninterrupted action, and consequently he conserves it not as it might have been at some earlier time but precisely as it at the very instant he conserves it" (AT 11 44; CSM 1 96). According to Descartes, such an operation will produce a constant rectilinear tendency because straight-line motion is "entirely simple and has a nature which may be wholly grasped in an instant" (Ibid.). But notice that this is false if God instantaneously determines the body to proceed along some *particular* straight path, since "grasp" of that path would require that some additional point or part of the line be specified.²² So perhaps what God always determines is merely that the body henceforth perseveres along *some straight path or other*. Such a determination would not, however, lead to the production of rectilinear motion. For by this entirely simple action he could produce curvilinear motion simply by giving *different* rectilinear tendencies to the body over time. To use an analogy, suppose a cook follows two recipes on different occasions. The first recipe requires her to add a pinch of salt, stir, add another pinch of salt, stir, and so on. The second recipe is the same, except that the cook stirs in a series of different ingredients: salt, cumin, coriander, etc. Intuitively, the first recipe is simpler, as will be the bland dish that results. But if the cook is always concerned exclusively with the step in the recipe she is currently following, and has all the necessary ingredients readily at hand, then her *action* does not seem any simpler in preparing the first dish. Likewise, the

22. Malebranche seems to make this mistake in his defense of rectilinear motion: "circular motion is not simple; we cannot conceive of it without thinking of a point to which the body moved, rather than the motion, is related; and everything that contains a relation is relative and not simple" (Malebranche 1980, p. 468). By the same token, rectilinear motion in some direction is not simple either. It also seems fair to ask (with Peter Machamer) "why he [God] should consider two points simpler than three, given his infinite wisdom" (Machamer 1976, p. 190). Even in our own case, the complexity of a line does not present a significant barrier to our comprehension of it. Thus, in the second book of his *Geometry* Descartes presents a method for tracing curves that are more complex than circles. Since the procedure is entirely exact and deterministic, the more complex curves can be understood just as well as the simpler ones: "I can see nothing to prevent us from conceiving the description of [the more complex curve] AD as clearly and distinctly as that of the circle" (AT 6 392; O, 192).

requirement of simplicity does not appear to entail that continuous determination of rectilinear tendency must generate rectilinear motion.

Perhaps this is why immutability is needed in addition to simplicity: God's action would change if he gave bodies different rectilinear tendencies over time.²³ But to invoke immutability in this way seems to invite the unwelcome consequence that a body in non-rectilinear motion always perseveres in the same direction, contrary to the very observations Descartes uses to illustrate and confirm the second law. For example, in the swinging stone case he says that what is determined at each point A along the circular path of the stone ABF is a tendency to move along the tangent AC (see Figure 1). But as the stone moves this tangent is at each instant in a different direction.²⁴ So God's action in determining the rectilinear tendency of the stone appears to be no more uniform, assuming the directional criterion of simplicity, than if he were always determining a circular tendency. Indeed, if we move to the limit, his actions are identical in the two cases.²⁵ So the evident simplicity of the operation by which God gives rectilinear tendency to moving bodies is insufficient, even combined with

23. Stephen Menn's own brief account of the proof, which is presented in the context of an illuminating historical discussion of divine conservation of motion, is in this spirit: "at each instant what God creates in a body is a bare inclination to move with a certain speed in a certain direction, not rectilinearly or circularly or in any other determinate way; but at each instant God renews in this body an inclination to move with the same speed and in the same direction, and so he produces a uniform rectilinear motion" (Menn 1990, pp. 232–3). It is hard to see how this "bare inclination" view can be squared with the text, since Descartes says explicitly that "clearly whatever is in motion is determined, at the individual moments that can be specified as long as the motion lasts, to continue moving in a given direction along a *straight line*" (AT 8A 64; CSM 1 242, my emphasis) and that the swinging stone "tends toward C when it is at point A [. . .] assuming AC to be *the straight line* which is the tangent to the circle at A" (AT 8A 109; MM 112, my emphasis). God gives to bodies not merely a bare inclination to move in a certain direction, but a determinate inclination to move in a straight line.

24. Granted, whatever Descartes' proof establishes, it does not establish that the rectilinear tendency will be along the tangent, as both Des Chene (1996, p. 281) and Garber (1992, p. 220) observe. Indeed, Descartes himself sometimes suggests that the swinging stone has a tendency to move radially straight out from the center of rotation (AT XI 86; MM, 112) and sometimes even along its actual circular path (AT XI 85; MM 113). Des Chene offers a promising suggestion as to what might have motivated the tangential postulate. Descartes may have reasoned implicitly (as Rohault did later in print) that since a circle may be regarded as an infinitely sided polygon, with each side a different tangent of the circle, a body in circular motion may likewise be regarded as always deflected from its determination along a given side or tangent onto the "next" one. Hence, if the sling is released at point P, then its path will be along the tangent it was determined to follow at that point (Des Chene 1996, p. 282).

25. Against the Aristotelian preference for circular motion, Malebranche points out that "circular motion would be infinitely complex, since all the tangents of the circle lead in different directions" (Malebranche 1980, p. 468) He doesn't seem to realize that the

immutability, to deliver a “clear and indubitable” foundation for the second law.

Descartes himself may have realized this, since appeal to the supposed simplicity of unidirectionality is dropped from the later *Principles* version of the proof (which is otherwise very similar to that given in *le Monde*). He does still mention, although without elaborating, the “simplicity” of God’s operation. But, as Gary Hatfield has suggested, he may mean simply that God’s action is instantaneous, i.e., “temporally simple” rather than simple in content or object.²⁶ What Descartes *does not* say any longer is that rectilinear motion is preferred because it can be specified by a single direction. Rather he simply asserts that whatever is instantaneously determined to move is determined “to continue moving in a given direction along a straight line, and never along a curved one” (AT 8A 64; CSM 1 242). And the reason he says rectilinear determination is preferred is because at any point A on the curved path of a body “none of its circular movement can be understood to remain in it when it is at point A” (AT 8A 64; MM 61). So the issue in the *Principles* becomes squarely what sort of tendency can possibly be produced by God *at an instant* rather than what sort of divine operation is the simplest. It is this relationship between God’s action and time that Des Chene’s reading fails to account for. In both versions of the proof, Descartes emphasizes that God conserves the motion in bodies only as it is at the very instant he conserves it, and without “taking account” of any earlier motions. But if the issue were simplicity rather than temporality God would be compelled to produce rectilinear determination even if he took full account of earlier motions, and indeed even if he determined motion only at the beginning of the world rather than by continuous conservation.

Daniel Garber’s reconstruction of the proof of the second law focuses more directly on the nature of God’s continuous conservation of motion. Rejecting what he calls the “cinematic view” that God produces motion simply by successively re-creating bodies at different places, Garber proposes instead that God conserves a certain impulsion or “shove” which is the primary and universal cause of all motions. And rectilinear tendency, he contends, is just what one should expect on this “divine shove” model. In particular, the assumption that everything required to produce motion is “present at each instant” (AT 11 97; CSM 1 97) implies that God’s shove will always be along a straight line.

same argument shows that God’s operation must be infinitely complex in always giving a new rectilinear tendency to bodies moving in a circle.

26. Hatfield 1979, p. 123, note 48.

That is, at any instant, the shove that produces the motion in time can only be a shove in some one determinate direction. A succession of shoves can move the body in a curvilinear path, but any individual shove at a particular moment can push it in only one direction. It is in this sense that only rectilinear motion can be comprised in an instant, and in an instant only that required to produce rectilinear motion can be found (Garber 1992, p. 286).

Assuming God's immutability prevents him from shoving successively in different directions, this interpretation secures inertial rectilinear motion.

Garber's reading takes better account of the role that time plays in Descartes' proof. The idea is that because God must at each instant give everything to the body that is needed for its motion, he can only "instantaneously shove" in one direction. But the weakness in Garber's account is precisely that it fails to justify this crucial assumption. What is to keep God, the defender of circular motion will ask, from always giving to bodies a proper tendency to follow a circular path, like the celestial "movers" of Aristotelian cosmology? It does not seem that God's immutability would be sacrificed if he were to do so, providing he confines himself to the same "curvilinear shove" over time. If God can always give bodies what is sufficient to follow a straight trajectory, why couldn't he always give them what is sufficient to follow a curved one? This is the question I will attempt to answer in the next section.²⁷

27. A number of commentators have suggested that the proof depends on a discontinuous or "atomistic" conception of time. For example, Gaukroger says about the *le Monde* proof: "The argument here relies on the motion being conceived of in terms of a discontinuous series of instants, for if it is conceived of as something continuous then the required distinction between rectilinear and circular motion cannot be made" (WO 30, note 39). See also Nadler (1990, p. 368 note 17) and Blackwell (1966, p. 224). Gaukroger's point seems to be that if time and motion are continuous, then rectilinear motion can no more be "conceived in an instant" than curvilinear motion, since there would be no smallest part of time in which this instantaneous (rectilinear) tendency could be conceived. Thus, he goes on to emphasize that "Descartes' commitment to the discontinuous nature of motion derives above all else, from his early work in hydrostatics where [...] it is instantaneous tendencies to motion, rather than motion proper, that is the central concern" (WO 30, note 39). This argument seems to assume that one can speak of an instantaneous feature of a moving body only if time and motion are discontinuous. But why assume that? For one can consider the "individual instants" of time at which bodies have only tendencies to (rectilinear) motion, rather than actual motion, as the boundaries of any arbitrarily chosen part of continuous time. Thus, the instantaneous tendency is at the boundary of the resulting rectilinear motion. I share Garber's view (1992, pp. 287–8) that Descartes' proof is neutral on the question of temporal continuity.

4. Time, Causation, Direction

My reading of the proof of the law of rectilinear motion will depend on the assumption that it is metaphysically impossible for God to give to bodies an instantaneous tendency to later change in some respect. Such an assumption is invoked briefly, for somewhat different purposes, by Gary Hatfield in his (1979) paper on force in Descartes' physics. In defense of his view that for Descartes God is the immediate source of all bodily motions, Hatfield says that Descartes could not have made the relation between God and the law-governed motions of bodies less direct than this by supposing that God merely decreed the laws at the beginning of the universe, with matter forever afterwards following that decree. For "unless matter forever after *remembered* the decrees and *understood* them well enough to carry them out, this would require that God's decrees act at a temporal distance, which is as unacceptable as having the matter follow the laws intentionally" (Hatfield 1979, p. 127, note 58).²⁸ It is unclear why Hatfield thinks that in order to avoid "decreeing at a temporal distance" God would need to give memory and understanding to matter. We need not assume, for example, that a baseball pitcher gives memory and understanding to the ball when he throws a curve. He may simply give the ball a curvilinear tendency, which is not later defeated by other forces. Perhaps Hatfield would label this "decreeing at a temporal distance." But then the question is why this should pose any difficulty, especially for God. In what follows, I will argue that Descartes had what he took to be a clear and distinct reason, based on the very nature of causality, why God could not give to bodies a curvilinear tendency, and so could not in that sense decree at a temporal distance.

I would like to focus attention on Descartes' assumption that God "always conserves the motion in the precise form in which it is occurring at the very moment when he preserves it, without taking account [*nulla habita ratione*] of the motion which was occurring a little while earlier" (AT 8A 64; CSM 1 242). Although the precise import of this premise is not immediately obvious, it does seem that neither Des Chene's nor Garber's interpretation explains why Descartes would rely on it. As I argued above, if Des Chene is right that God conserves rectilinear tendency because the resultant motion is the simplest, then there would be no need to insist that God attends strictly to the present tendency. According to the unidirectional criterion of simplicity, rectilinear motion should be

28. Compare Robert Boyle: "I cannot conceive how a body devoid of understanding and sense, truly so called, can moderate and determine its own motions, especially so as to make them conformable to laws that it has no knowledge or apprehension of" (Boyle 1990, p. 181).

simpler than circular motion regardless of whether the source of the motion gives any consideration to earlier states of motion. Garber suggests that God cannot, at an instant, give bodies a “curvilinear shove.” But why would curvilinear shoving be easier for God if he took account of the earlier motions of bodies?

In order to understand what Descartes has in mind when he says that God takes no account of the earlier motions of bodies when he conserves their current motions, we need to examine briefly how Descartes conceives of “the operation by which God conserves motion in matter” (AT 8A 64; CSM I 242). For this operation, he tells us, is the foundation for all three laws of nature, as well as the principle of the conservation of motion. When he introduces the laws, Descartes explains that God is the “universal and primary” cause of all motions in the world. In the beginning, God created all the matter, along with its motion and rest “and now by his regular concurrence he preserves the same amount of motion and rest as he put there in the beginning” (AT 8A 61; CSM 1 240). Descartes does not mean to suggest that in now lending his regular concurrence to the world, God is no longer directly involved with its operation. On the contrary, God is always doing precisely what he did at the beginning: “God imparted various motions to the parts of matter when he first created them, and he now preserves all this matter in the same way and by the same process by which he originally created it” (AT 8A 62; CSM 1 240). In other words, in conserving matter and motion God continues to create them: “God preserves the world by the selfsame action and in accordance with the selfsame laws as when he created it” (AT 8A 66; CSM 1 241).

The notion that God must continually create the world is defended in the Third Meditation and in Part I of the *Principles*. In both texts, the argument turns crucially on a certain fact about the nature of time: “For the nature of time is such that its parts are not mutually dependent, and never co-exist. Thus, from the fact that we now exist it does not follow that we shall exist a moment from now, unless there is some cause—the same cause that originally produced us—which continually reproduces us, as it were, that is to say, which keep us in existence” (AT 8A 13; CSM 1 200).²⁹

29. In the Third Meditation: “For a lifespan can be divided into countless parts, each completely independent of the others, so that it does not follow from the fact that I existed a little while ago that I must exist now, unless there is some cause which as it were creates me afresh at this moment—that is preserves me. For it is quite clear to anyone who attentively considers the nature of time that the same power and action that are needed to preserve anything at each individual moment of its duration would be required to create that thing anew if it were not yet in existence” (AT 7 AT 7 49; CSM 2 33). See also AT 8A 13; AT 7 109, 165, 370; AT 5 53; AT 5 155; CSM 1 200; CSM 2 78–9, 116, 255; CSMK 320; CB 16.

The argument obviously applies to bodies as much as finite minds, as Descartes explains in his replies to the First Set of Objections: “The separate divisions of time do not depend on one another. Hence the fact that the body in question is supposed to have existed up until now ‘from itself’, that is, without a cause, is not sufficient to make it continue to exist in the future, unless there is some power in it that as it were recreates it continuously” (AT 7 110; CSM 2 79). From this mutual independence of the parts of time or duration it follows for Descartes that the temporal stages of created things are also independent, since the distinction between a substance and its duration is merely a conceptual one (AT 8A 30; CSM 1 214).³⁰

But why believe that the temporal stages of created things are mutually independent? Certainly they are logically independent, but that does not indicate a continuous creator is needed since earlier stages might be causally sufficient for later ones even if they do not entail them.³¹ Descartes’ view must therefore be that no given temporal part of a thing is causally sufficient any later part. And the reason he holds this seems to be because causes and effects are necessarily simultaneous: “The natural light does not establish that the concept of an efficient cause requires that it be prior in time to its effect. On the contrary, the concept of a cause is strictly speaking applicable only for so long as the cause is producing the effect, and so it is not prior to it” (AT 7 108; CSM 2 78).³² If a cause cannot be prior to its effect, and if the duration of any created thing is divisible into countless non-simultaneous stages, it follows that no stage can be causally sufficient for any later stage. Therefore, if we assume, as Descartes does, that everything has a cause,³³ it follows that finite minds, matter, and motion, must all be continually created by something which needs no external cause.³⁴

30. Since there is no real distinction between a substance and its duration, it follows that no time could pass either before the creation of the world or after its annihilation (AT 5 343; CSMK 373).

31. Yet this seems to be how Gilson understands the argument: “the existence or state of a thing at one moment does not in itself provide a sufficient reason for the existence or state of the thing in the very next instant” (Gilson 1925, p. 340). Similarly, Richard Arthur writes: “According to Descartes, the world, created by God with a certain force in the very first moment of time, requires the same force and action to keep it in existence at each subsequent moment, since there is no principle inherent in any substance by which its existence at a later time might follow from its existence at any earlier time” (Arthur 1988, p. 352). See also Anderson 1976, p. 207.

32. He repeats the point elsewhere, without elaborating (see AT 7 240; CSM 2 167). I develop this interpretation of the temporal independence thesis in more detail in another paper (Gorham 2004).

33. AT 7 112, 165; CSM 2 80, 116.

34. Descartes’ defense of the causal simultaneity condition is obscure. He says that the

So Descartes' laws of motion are based on a strong version of the traditional doctrine of continuous creation, which in turn depends on a metaphysical thesis about the relation between time and causality. Let me now indicate the importance of this picture for understanding the argument for rectilinear motion, particularly the puzzling premise about God not "taking account" of earlier motions. Certainly, Descartes is not saying that God is *unaware* of these earlier motions. Rather, he is saying that these motions can play no role in determining the motions or tendencies, which God gives to the body at the present time. For if there was in this way a dependence of the present state of the world on an earlier state, then the condition of causal simultaneity would be violated. In other words, God cannot produce motion in time by giving some tendency to bodies, perhaps at the beginning of the universe, which will result in it later having some specific tendency or directional determination. He can only produce motion in time by giving to bodies always a tendency which is sufficient to make them move at that time, if they could move at an instant, regardless of whatever motions they had at any earlier times.³⁵

Now Descartes' explicit view is that only rectilinear motion is of such a nature that everything sufficient for it, i.e., its corresponding proper tendency, can exist at an instant: "I am not saying that rectilinear motion can take place in an instant, but only that everything that is required to produce it is present in bodies in each instant while they are moving, while

concept of a cause only applies when something is actually producing its effect, but doesn't explain why the effect needs to be produced right away. It seems he regarded diachronic causal processes unintelligible in the same way as action at a (spatial) distance. Thus, in a letter to Hyperaspites he argues that the "whip" cannot be considered to be the cause of the spinning of the top: "For I admit that I am not subtle enough to understand how something that is present can be acted upon by something else that is not present—which may indeed be supposed not to exist anymore, like the whip if it should cease to exist after whipping the top" (AT 3 428; CSMK 192). Another possible justification is that if the effect is any later than the cause then something else must have been needed to produce the effect. Thus, Hume observes: "Tis an establish'd maxim in both natural and moral philosophy that an object which exists for any time in its full perfection without producing another, is not its sole cause" (Hume 1978, p. 76).

35. In a recent discussion Gaukroger correctly states that the Third Meditation proof of our dependence on God is based on the principle of causal simultaneity. But he goes on to suggest that physical processes do not satisfy this principle, since "Descartes believed that bodies remained in inertial states, such as rectilinear motion, without external causes" (2002, p. 78, note 15). This leads him to wonder how Descartes can allow the condition of causal simultaneity to be violated in the case of physical interaction while not allowing this in the case of existence *per se*. But Gaukroger's worry is misplaced. According to Descartes, the laws of nature hold only because God must create the universe at all times. So the condition of causal simultaneity, far from being incompatible with Descartes' laws of nature, is actually the metaphysical foundation for those laws.

not everything that is required to produce circular motion is present” (AT 11 45; CSM 1 97). What more would be required to be present in a body at some time in order to produce curvilinear motion? It would need to have at that time a proper tendency to move in the various different directions that determine its curved path over time. Suppose, for example, that a body at some time possessed a proper tendency to follow a certain curved path ending at some point in the northeast. Then it would need to have various northerly and easterly directional determinations, since its actual path would be along these different directions (if it were the only body). But it could not have all of these tendencies at the outset. For suppose, to simplify, that the path of the curve is first east and then north. If it had the tendencies to go north and east both at the outset, then its tendency at that time would simply be to go northeast, rather than to follow some specific curve. Alternatively, the body is given at the outset is a proper tendency to first go east and then go north. But, in that case, God would need to give to bodies some feature at the outset which is the cause of a later change in its determination, contrary to the principle of causal simultaneity. So, the reason “not everything required to produce circular motion is present” in each instant is because then the cause of some later change (of direction) would be already present in each instant. But, as Descartes says, the concept of a cause is applicable only when the cause is producing the effect, and so the cause cannot be prior to the effect.

From this perspective, Descartes’ position is really that there could be no such thing as a proper and instantaneous curvilinear tendency. That is why he does not any longer harp on the relative complexity of curves by the time of the *Principles*, and emphasizes instead the inconceivability of curvilinear tendency. Thus, when a moving body is at a given point A on a circular path “we *cannot conceive* that is inclined to any circular movement: for although it will have previously come [...] along a curved line, none of this circular movement *can be understood* to remain in it when it is at point A” (AT 8A 64; MM 61, my emphasis). We cannot conceive a body having a circular tendency because we cannot conceive of a body now having the power to produce a later change in its directional determination. Nor, looking in the other temporal direction, can we imagine how the tendency or motion that the body had earlier can be responsible for the swerve we now observe. Those earlier motions can have no part in a correct “account” (*ratione*) of the current motions. If this is why Hatfield thinks that God cannot “decree at a temporal distance” and why Garber thinks God cannot “shove around corners,” then I agree with them.

As for rectilinear motion, Descartes does think “everything required to produce it is present in bodies at each instant” (AT 11 45; CSM 1 97). For to produce rectilinear motion it suffices to give the body an inclination

such that it would actually move in a certain direction were it isolated and were it to move in that instant (though nothing can move in instant, as Descartes emphasizes). This would not require giving to the body a power to produce later movements, much less later changes in direction, either of which would violate the condition of causal simultaneity. Rather, the action would consist simply in giving the body a single directional determination at the present time. It seems to me that this is the idea that Descartes means to highlight when he says in *le Monde* “of all motions, only motion in a straight line is entirely simple and has a nature which may be wholly grasped in an instant” (AT 11 45; CSM 1 97). Once the primacy of rectilinear tendency is established, God’s immutability comes into play. For if we assume that at the first instant of creation God can only give to bodies a rectilinear proper inclination, and that his action never changes after that, it will follow that bodies will always properly tend to move in straight lines, as experience confirms.

5. Conclusion

I have argued that unless one attends to the metaphysical underpinnings of Descartes’ physics, especially his conceptions of time and causality, and their relation to God’s operation, it will be difficult to understand his proof of the law of rectilinear motion. That proof, both in its early *le Monde* presentation and in its more exact *Principles* formulation, appeals to the fact that God is concerned only with the present state of the world as he creates it, and does not “take account” of any earlier state. I have attempted to show that this crucial feature of the proof derives from Descartes’ condition of causal simultaneity, which has an important role in establishing his doctrine of continuous creation. Granted this reading does not solve every puzzle about Descartes’ proof of rectilinear motion. Like Des Chene’s, it assumes that motion along a curved path necessarily involves changes of direction. And it does not explain why God’s operation is not in fact highly mutable given Descartes’ assumption that it is tangential tendency, which is always preserved in circular motion. Nevertheless, my account makes some sense of the otherwise perplexing role of time in the proof and also reveals one important respect in which Descartes’ physics is rooted in fundamental metaphysics.

References

- Anderson, Wallace E. 1976. “Cartesian Motion.” Pp 200–23 in *Motion and Time, Space and Matter*. Edited by Peter Machamer and Robert Turnbull. Columbia: Ohio State University Press.
- Arthur, Richard. 1988. “Continuous Creation, Continuous Time: A Refu-

- tation of the Alleged Discontinuity of Cartesian Time." *Journal of the History of Philosophy*, 26: 349–375.
- Blackwell, Richard J. 1966. "Descartes' Laws of Motion." *Isis*, 57: 220–34.
- Boyle, Robert. 1990. *Selected Philosophical Papers of Robert Boyle*. Edited by M. A. Stewart. Indianapolis: Hackett Publishing Co.
- Broughton, Janet. 1987. "Necessity and Physical Laws in Descartes' Philosophy." *Pacific Philosophical Quarterly*, 68: 205–21.
- Clarke, Desmond. 1982. *Descartes' Philosophy of Science*. Manchester: Manchester University Press.
- Della Rocca, Michael. 1999. "If a Body meets a Body: Descartes on Body-Body Causation." Pp 48–81 in *New Essays on the Rationalists*. Edited by Rocco Gennaro and Charles Huenemann. Oxford: Oxford University Press.
- Des Chene, Dennis. 1996. *Physiologia: Natural Philosophy in Late Aristotelian and Cartesian Thought*. Ithaca: Cornell University Press.
- Descartes, René. 1965. *Discourse on the Method, Optics, Geometry, and Meteorology*. Edited by Paul J. Olscamp. Indianapolis. Bobbs - Merrill.
- . 1976. *Descartes' Conversation with Burman*. Edited by John Cottingham. Oxford: Clarendon Press.
- . 1996. *Oeuvres de Descartes*. 11 Volumes. Edited by Charles Adam and Paul Tannery. Paris: J. Vrin.
- . 1983. *Principles of Philosophy*. Edited by Valentine R. Miller and Reese P. Miller. Dordrecht: D. Reidel Publishing Company.
- . 1985. *The Philosophical Writings of Descartes*. 2 Volumes. Edited by John Cottingham, Robert Stoothoff, and Dugald Murdoch. Cambridge: Cambridge University Press.
- . 1991. *The Philosophical Writings of Descartes: The Correspondence*, Edited by John Cottingham, Robert Stoothoff, Dugald Murdoch and Anthony Kenny. Cambridge: Cambridge University Press.
- . 1998. *The World and Other Writings*. Edited by Stephen Gaukroger. Cambridge: Cambridge University Press.
- Gabbey, Alan. 1980. "Force and Inertia in the Seventeenth Century: Descartes and Newton." Pp 230–320 in *Descartes: Philosophy, Mathematics and Physics*. Edited by Stephen Gaukroger. Brighton: Harvester Press.
- Garber, Daniel. 1992. *Descartes' Metaphysical Physics*. Chicago: University of Chicago Press.
- Gaukroger, Stephen. 2002. *Descartes' System of Natural Philosophy*. Cambridge: Cambridge University Press.
- Gilson, Etienne. 1925. "Commentaire Historique" sur *Descartes' Discours de la Méthode*. Paris: J. Vrin.
- Gorham, Geoffrey. 2004. "Cartesian Causation: Continuous, Instanta-

- neous, Overdetermined." *Journal of the History of Philosophy*, 42: 389–423.
- Hatfield, Gary. 1979. "Force (God) in Descartes' Physics." *Studies in History and Philosophy of Science*, 10: 113–40.
- Hume, David. 1978. *A Treatise of Human Nature*. Second Edition. Edited by L. A. Selby-Bigge Oxford: Oxford University Press.
- Machamer, Peter. 1976. "Causality and Explanation in Descartes' Natural Philosophy." Pp 168–199 in *Motion and Time, Space and Matter*. Edited by Peter Machamer and Robert Turnbull. Columbia: Ohio State University Press.
- Malebranche, Nicholas. 1980. *The Search after Truth*. Translated by Thomas Lennon and Paul Olscamp. Columbus: Ohio State University Press.
- McLaughlin, Peter. 2000. "Force, Determination and Impact." Pp 81–112 in *Descartes' Natural Philosophy*. Edited by Stephen Gaukroger. London: Routledge Publishing Company.
- . 1993. "Descartes on Mind-Body Interaction and the Conservation of Motion." *The Philosophical Review*, 102: 155–182.
- Menn, Stephen. 1990. "Descartes and Some Predecessors on the Divine Conservation of Motion." *Synthese*, 83: 215–238.
- Nadler, Steven M. 1990. "Deduction, Confirmation, and the Laws of Nature in Descartes' *Principia Philosophiae*." *Journal of the History of Philosophy*, 28: 359–83.
- Régis, Pierre Sylvain. (1690) 1970. *Cours Entier de Philosophie*. 3 Vols. New York: Johnson Reprints.
- Rohault, Jacques. (1723) 1969. *System of Physics*. Translated by J. Clarke. New York: Johnson Reprints.
- Slowik, Edward. 2002. *Cartesian Spacetime*. Dordrecht: Kluwer Academic Publishers.
- Westfall, Richard. 1971. *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century*. New York: American Elsevier.
- Williams, Bernard. 1987. *Descartes: The Project of Pure Inquiry*. London: Penguin Press.