DANIEL GARBER

9 Leibniz: physics and philosophy

Understanding the physical world was one of Leibniz's central interests. Earlier chapters of this *Companion* have explored aspects of Leibniz's metaphysics as they developed, his account of substance in general, and corporeal substance in particular. But Leibniz's interest in the physical world did not stop with metaphysics. Among his writings are numerous letters, notes, essays, and more extended treatments of questions in physics that show his deep engagement with the science of his day. Leibniz was one of the most important physicists of the late seventeenth century; other than Sir Isaac Newton, there is probably no other physicist of his generation who contributed more to the new mathematical physics. Thus, to understand the history of science in this crucial period, we must understand Leibniz's thoughts on physics. For Leibniz, as for many of his contemporaries, there was no clear boundary between philosophy and physics; understanding the world was at issue, and often those involved in what we would call philosophical projects to understand the world were also deeply involved in what we would consider scientific projects as well. Descartes, for example, the great philosopher of the earlier seventeenth century, made important contributions in his writings to mathematics and physics, as did Bacon, Hobbes, Gassendi, and later, Berkeley. Leibniz's physics and his philosophy were deeply intertwined; to try to study the one without the other is to get only a partial and inadequate picture of his thought.

In this essay, I shall outline the foundations and main features of Leibniz's thoughts on physics. After discussion of the state of physics in the late seventeenth century and of the historical development of Leibniz's thought, I shall discuss his science of dynamics and the self-consciously metaphysical notion of force central to that science.

I shall then turn to physics proper and discuss Leibniz's conception of space, motion, and the laws of motion, ending with a discussion of the relations between the domain of physics and other domains of Leibniz's concern.[1]

I. ARISTOTELIANISM, MECHANISM, AND LEIBNIZ'S EARLY PHYSICS

The seventeenth century was a period of rapid development in the sciences, the period in which the Aristotelian science that dominated the Middle Ages and the Renaissance schools was replaced with what was soon to become classical physics. In the beginning of the century, every student learned physics from Aristotle,· only one hundred years later, Newton was the new master.

Aristotelian physics was a matter of some complexity, but to understand the intellectual transformation in which Leibniz participated, we must understand something of its starting place. For the Aristotelian physics, the basic explanatory principles were matter and form. Together, matter and form were taken to compose body. Matter is what remained constant in change, while form is what changed when a body changed its properties; accidental form explained changes in accidents (from brown to yellow hair, from hot to cold), while substantial form explained changes in substance, from air to water, or from prince to frog. Thus, for the Aristotelian physicist, the characteristic properties of bodies were explained in terms of these forms and were thought of as innate tendencies bodies have to behave in one way or another; stones were thus thought to fall, and fire to rise, fire to heat, and water to cool by virtue of the forms that the bodies in question have.[1]

While Aristotelian natural philosophy was controversial from its first reintroduction into Western Europe in the late twelfth and early thirteenth centuries, by the beginning of the seventeenth century it had become the orthodoxy in the schools.[3] But early in the seventeenth century, it came under a new kind of attack from proponents of the new mechanical philosophy. According to this new philosophy, the only explanatory principles in physics were size, shape, and motion. It was held that the properties of bodies are to be explained, not in terms of form, accidental or substantial, but in terms of the broadly geometrical properties of the tiny particles that make up larger bodies, in terms of the motion of tiny corpuscles of different sizes and shapes, whose motion changed through collision alone. And so, heat and cold are to be explained not in terms of form, but of the shape of the particles that make up a body or the speed with which they move; heaviness is to be explained not in terms of an innate tendency to fall, but in terms of the collision between a falling stone and the particles in the atmosphere that push it downward. This new billiard-ball world was the work of many in that century, including Galileo, Descartes, Hobbes, Huygens, Gassendi, and others. For some it was linked to the doctrines of the ancient atomists with their unsplittable atoms swimming in a void, while others saw infinitely divisible material substance swimming in a plenum; for some it was linked with the framing of precise mathematical laws, while others were content with more general and less precise descriptions of the behavior of bodies; for some it was experimental, while for others it was largely *a priori.* There was also profound disagreement about just how new this new mechanical philosophy really was. While some adherents represent it as quite revolutionary, many, including Leibniz in some parts of his career, represent it as continuous with Aristotelian thought, consistent with either medieval Aristotelianism or with what Aristotle himself originally intended, however much Aristotle's thought may have been distorted by later thinkers.[4]

It is against this background that we must view Leibniz's thought in physics. Leibniz's earliest reading and education was certainly in the Scholastic tradition, and it is no doubt Aristotelian physics that he first learned.[5] But when he was only fifteen, if his own testimony is to be trusted, Leibniz turned toward the Moderns.[6] Nothing survives from this very earliest mechanist period which would have commenced in 1661. By the mid- and late 1660s, there is ample evidence of Leibniz's interest in the new mechanical philosophy.[7] Most important in these very early years are two letters that Leibniz wrote, in 1668 and 1669, to his mentor, Jacob Thomasius, in which he discusses the new mechanists (A Il.i no. 9 and 11). Like many of the new mechanists, Leibniz saw the nature of body as consisting of its broadly geometrical properties, extension and antitypy (impenetrability) (see A Il.i 23: L 101). Like many mechanists, particularly the Cartesians, Leibniz also seems to have flirted with occasionalism at this stage, and told Thomasius that only God has the ability to move bodies by continually recreating them in different places at different times (see A ILi 23-4: L 101-2).[8] Referring to such new philosophers as Descartes, Bacon, Gassendi, Hobbes, and Digby, Leibniz declares: "I maintain the rule which is common to all of these renovators of philosophy, that only magnitude, figure, and motion are to be used in explaining corporeal properties" (A ILi is:L 94).

Though Leibniz was clearly an adherent of the new mechanical philosophy by the late 1660s, there is no reason to believe that he thought that his brand of mechanism was in any way inconsistent with an adherence to Aristotelian philosophy. Indeed, in the April 1669 letter to Thomasius, Leibniz emphasizes over and over again that while the new philosophy may be inconsistent with the teachings of the Schoolmen, it is fully consistent with the teachings of Aristotle himself; when properly understood, Leibniz argues, Aristotle too was a mechanist of sorts (A ILi no. n: L 93-103). Recent studies of these texts have also suggested that Leibniz's concept of substance in these years is best thought of in Aristotelian terms, in terms of matter and form. As noted earlier, during this period Leibniz held that the essence of body is extension and impenetrability, as many mechanists did. However, unlike run-of-the-mill mechanists, Leibniz combined this view with an Aristotelian view of substance, holding that bodies only constitute substances when taken together with concurrent minds, in particular, the mind of God, who is the source of activity in the world.» All in all, it seems best to view Leibniz in the context not of the radical mechanists, but of the renovators or reformers, of the seventeenth century thinkers who were attracted to the new mechanical philosophy while at the same time thinking that it could be reconciled with the old Aristotelian physics. For Leibniz in this period - and, as we shall see, for the rest of his career as a physicist - the view was that the true physics must somehow be a blend of the old and the new, a physics that was at the same time Aristotelian and mechanist.[10]

Early indications of Leibniz's interest in the new mechanical physics are programmatic and unsystematic. The first indication of any serious and systematic interest in physics on Leibniz's part isn't found until late 1669. Then begins a series of notes on questions in physics, mainly the theory of motion, that lead to Leibniz's first substantial writings in physics, the *Hypothesis physica nova* (HPN) or *Theoria motus concieti,* presented to the Royal Society of London in 1671, and the *Theoria motus abstiacti* (TMA), presented to the French Academy of Sciences that same year.[11]

Together these works constitute an interesting system of physics. In the TMA, Leibniz gives an abstract account of motion, as the title suggests, an account of motion that is grounded purely in reason, so Leibniz claims. But such an account of motion is radically in contradiction with the everyday experience of bodies and with the more exact experiments of other investigators. Leibniz's solution to this apparent inconsistency between reason and the world is a hypothesis about the state of the universe God created, which, together with the abstract laws, yields something close to what it is that we observe in the world; this is the task of the HPN, or the theory of concrete motion, as the subtitle suggests, a theory of motion for *our* world (A Vl.ii 223I,.[12]

The heart of Leibniz's abstract theory of motion in the TMA is an account of the collision of two bodies; for Leibniz, as for other mechanists, collision is the only way in which the motion of a body can be changed naturally. The account of impact is given in terms of the notion of a *conatus,* an indivisible, nonextended part of motion, the beginning or end of motion, as he puts it (A Vl.ii 264-65: L 139-40).[13] Leibniz constructs his abstract theory of motion on the conviction that the outcomes of collisions are determined by simply combining the instantaneous motions (*conatus*) of the two bodies at the moment of collision,· body as such offers no resistance to motion and so the mass or size of the bodies in question plays *no role whatsoever* in the outcome of a collision. As Leibniz put it in the HPN, "all power in bodies depends on the speed" (A Vl.ii 228). If two bodies with unequal speed collide, then, Leibniz argues, the two will move together after the collision with a speed which is the difference between the two, and in the direction of the faster. In particular, if a moving body A hits a body *B* at rest, then they both move off in the direction the body *A* has, no matter how small *A* is, and no matter how large the resting *B* might be; in this case, the body *B* offers no resistance whatsoever to being set into motion. When the two speeds are equal, then "the directions of both will be destroyed, and a third will be chosen intermediate between the two, the velocity of the *conatus* being conserved, " a conclusion that Leibniz argues is "the peak of rationality in motion." He justifies his conclusion by an appeal to the principle that "there is nothing without reason." This is very likely the first time that Leibniz appealed in print to this most fruitful of his principles.[14] An interesting special case occurs when two bodies with the same speed collide directly. In this case, both come to a halt, in violation of the Cartesian conservation principle, in accordance with which the total quantity of motion (size times speed) is conserved in the world in general and in every individual collision.[1]?

These laws of motion, reasonable as they might be in the abstract, fit very poorly with the world we see around us, as Leibniz knew; in particular, the bodies of our world do seem to offer resistance to being set into motion. In the HPN these abstract laws are reconciled with experience through an hypothesis about the makeup of the world. As his earlier writings might suggest, the spirit behind the HPN is thoroughly mechanistic. Leibniz writes:

> I agree completely with the followers of those excellent gentlemen, Descartes and Gassendi, and with whomever else teaches that in the end, all variety in bodies must be explained in terms of size, shape, and motion.
> (HPN sec. 57; A VI.ii 248; cf. A VI.ii 249-50)

Leibniz's procedure in the HPN is very reminiscent of the creation story that Descartes told some years earlier.[16] Descartes' strategy was to derive the present state of the world from an initial creation and the laws of motion. Leibniz, too, starts at the beginning with an assumed first state, a solar and a terrestrial globe (he ignores the other planetary bodies, large and small), which are set into motions of various sorts and result in these two bodies rotating, each around its own axis, and revolving around each other, with light streaming from the sun to the earth (HPN sees. i-io; A Vl.ii 223-36). Leibniz argues that the impact of the light against the surface of the earth results in the production of tiny balls of matter. This is a crucial step in the theory. For, Leibniz argues, "these . . . balls are the seeds of things, . . .the foundation of bodies, and the ground of all of the variety that we admire in things, and all of the impetus we find in motions" (HPN sec. 12; A Vl.ii 226). The project, then, is to explain the main phenomena of the world in terms of these tiny balls or corpuscles. For example, Leibniz discusses the Aristotelian four elements (earth, water, air, and fire), showing how each can be generated from his theory (HPN sees. 13-14); gravity (HPN sees, isf.); color, sound, and heat (HPN sees. 30!); the magnet (HPN sees. 33bis f.); chemical reactions (HPN sees. 37!); density and rarity (HPN sec. 56); and others.

Of most interest to us in this context is the exact way the abstract laws of motion concerning bodies in impact are affected by the new hypothesis of the HPN. According to the abstract theory of the TMA, size or mass can play no role in the determination of the outcome of a collision. Furthermore, since at the moment of impact, the two bodies in impact will have exactly the same *conatus,* they will always move in the same direction at the same speed. But experience shows that bodies in the real world don't behave in that way; in every circumstance, the size or mass *does* play a role, and in most circumstances, bodies rebound in collision. Leibniz frames his hypothesis in such a way that in the world of the HPN, bodies acting in accordance with the laws of motion outlined in the TMA will behave as we see them behave. In the world of the HPN, the bodies of ordinary experience are made up of a multitude of tiny corpuscles. Imagine, now, a horizontal row of *n* tiny discrete balls, a_u a_2, etc., colliding with a single ball, *B,* moving in the opposite direction. Let us further suppose that *B* moves faster than the balls in row *A*. Consider, for example, the first ball, a_v hitting *B*. According to the laws of the TMA, the post-collision speed of *B* will be its precollision speed, minus the speed of a_v and the two balls will go off in the same direction at the same speed after the collision, i.e., the direction in which *B* originally moved. The pair of balls, a_T and *B* will then hit a_2, and the same thing will happen, that is, the speed of *B* will be further reduced. In this way, the speed of *B* will be reduced in the collision; if there are a sufficient number of balls, it can even be reversed. And so, in a discontinuous body, size (or, at least, the number of particles in the line of direct collision) *can* play a role in the outcome of a collision.[17] Similarly, Leibniz can appeal to his physical hypothesis (here the discontinuity of bodies, together with the ether that flows around their parts) to introduce elasticity in the world, thus enabling bodies to reflect from one another on occasion.[18] He wrote in the HPN:

> But by means of the wonderful handiwork of the creator, or through his gift, necessary for life, on our hypothesis all sensible bodies are elastic, due to the circulation of the ether, and therefore all sensible bodies reflect or refract. . . . Everything is discontinuous, from which it follows that other things equal, the greater mass accomplishes more; everything is elastic, that is, when compressed, and left to itself, it soon restores itself to its prior state on account of the circulating ether. (HPN sec. 22; A Vl.ii 229, 230)

Indeed, Leibniz thought that together his abstract laws and his physical hypothesis yielded the Huygens/Wren laws of impact, recently discovered and widely discussed. Writing on 13/23 July, 1670 to Henry Oldenburg, secretary of the Royal Society, which had published the Huygens/Wren laws and to which the HPN had been dedicated, Leibniz noted:

> For I have established certain elements of the true laws of motion, demonstrated in the geometrical method from the definitions of terms alone, . . . and this has also shown that those rules of motion, which the incomparable Huygens and Wren have established, are not primary, not absolute, not clear but, no less than gravity, follow from a certain state of the ter-aqueous globe, not demonstrable by axiom or theorem, but from experience, phenomena, and observation, however fertile and admirable . . . they might be.
>
> (A II.i 59. See also HPN sec. 23; A Vl.ii 23I-32)[1]»

And so, the laws bodies appear to obey in our world are are the result of abstract and geometrical laws, very different from what we experience in day-to-day life, operating in a complex world that God created for his ends.

The TMA and HPN are very important as the first systematic treatises in physics that Leibniz composed. But also of interest in these writings is an important metaphysical change from just a few years earlier. In the Thomasius letter of 1669, the nature of body is extension and impenetrability, but by the publication of the TMA, Leibniz's thinking is a bit different. Writing to Arnauld in November, 1671, announcing to him his new publications, Leibniz declares that the essence of body consists not in extension, or in extension and impenetrability, but in *motion* (A Il.i I72:L 149). Furthermore, with the TMA and HPN, Leibniz seems to give up the occasionalism of his earlier writings. As noted above, in the letters to Thomasius from 1668 and 1669, Leibniz held that God is the only real source of activity in the world and the real cause of motion in the physical world. But in these writings, this occasionalism is rejected and the cause of motion is moved from God to bodies themselves; bodies are, it seems, the sources of their own motion, which derives from their own minds, and these minds together with their bodies constitute genuine substances.[20] The rejection of occasionalism together with an unambiguous attribution of activity to substances in the world itself will be central to Leibniz's mature thinking about the physical world.

Leibniz's writings show continued interest in questions of physics throughout the decade, both during and after his important visit to Paris in 1672.[21] Though his intellectual world was rapidly expanding, his ideas in physics remain constant for a few years. In a long manuscript from 1672 that Leibniz entitled "Propositiones quaedam physicae" (A Vl.iii 4-72), one can find an attempt to present the basic theory of the HPN in a systematic and geometrical fashion, an enterprise that is repeated in an important letter to Honoratus Fabri in late 1676 (A Il.i 286-301). The Leibniz of 1671 can also be discerned in a fascinating set of notes that he wrote on Descartes' *Principles of Philosophy* in late 1675 or early 1676 (see A Vl.iii 213-17).[22] There he denies the Cartesian conservation law and substitutes his own view that it is *conatus* which is conserved, a view found in the writings of 1671. Similarly, against Descartes, he denies that bodies in and of themselves have any tendency to remain in the state in which they are, or resist the acquisition of new motion, repeating perhaps the most audacious claim made in the HPN and TMA, that the laws of collision are independent of size or mass (A Vl.ii 215-6). As Yvon Belaval put it, "it is, above all, the author of the *Hypothesis Physica Nova* who wrote these first reflections on the *Principles.* "[23]

Starting in 1676 Leibniz seems to have undertaken some serious rethinking of his views on the foundations of physics. The physics of 1671 recognizes no inherent resistance in bodies; size or mass play no role in determining the outcome of a collision between two bodies. It is evident that at the most basic level, the Cartesian law of the conservation of quantity of motion, size times speed, must be violated. But while the Cartesian conservation principle is not a *basic* law, Leibniz argues in a piece from December 1675 that in *this* world (i.e., the world of the HPN), full of matter, it is satisfied (A Vl.iii 466ff).[24]

There is reason to believe that Leibniz found a fatal flaw in Descartes' basic law less than a year later. In what is quite clearly a reference to his meeting with Spinoza in late 1676, Leibniz reports having set Spinoza right about the Cartesian laws of motion:

> Spinoza did not see the mistakes in Descartes' rules of motion; he was surprised when I began to show him that they violate the equality of cause and effect.[25]

For Leibniz the principle of the equality of cause and effect is the principle in accordance with which there must be exactly as much in the effect as there was in the cause, a principle that, as we shall see, has a crucial role to play in Leibniz's mature physics.[26] While the remark about what he showed Spinoza may be a bit cryptic, later writings suggest what Leibniz almost certainly meant: the Cartesian collision laws, governed by the principle of the conservation of quantity of motion, are inconsistent with the principle of the equality of cause and effect; if Cartesian quantity of motion is conserved in collision, then the ability the bodies had to do work before the collision can simply be lost after impact (see, e.g., letter to Theodor Craanen, June 1679, A Il.i 469-71).[27] And so, Leibniz implies, the Cartesian conservation principle must be wrong.

By January 1678, Leibniz seems to have gone a step further and replaced the Cartesian conservation law with one of his own. It was a consequence of Huygens' laws of impact that, in impact, the product of mass (size) and the square of the speed are the same, before and after the collision; indeed, Leibniz duly noted this in his own notes on Huygens on collision from late 1669, though it seems not to have made much of an impression on him at that time (see AVI.ii 158). But in a manuscript that can be dated precisely to January 1678, Leibniz takes this observation Huygens makes about bodies in impact and turns it into something central to his thought.[28] Leibniz came to hold in these years that in collision between bodies, the force or power of action must be conserved.[2»] What he discovered in January 1678 was that this force or power of action must be measured by mv^1.

As Leibniz later emphasizes, the replacement of the earlier physics of the TMA and HPN with a new physics grounded in the conservation of mv^2 was imbued with the greatest philosophical significance. Leibniz wrote a few years later in the *Discourse on Metaphysics* of 1686:

> This consideration, the distinction between force and quantity of motion, is rather important, not only in physics and mechanics, in order to find the true laws of nature and the rules of motion, . . . but also in metaphysics, in order to understand the principles better.
>
> (*Discourse,* par. 18., G IV 444: AG 51)

In particular, Leibniz argues that understanding the new conservation principle will lead us to appreciate that body and motion are to be grounded in what he calls force, something distinct from the notions of extension and motion that ground the Cartesian world (ibid.).[30]

Later we shall examine this claim more carefully. But it is worth pointing out that the new conservation law was not the only important change in Leibniz's views in these years. More generally, the abandonment of the basic strategy physics of the HPN and TMA, very likely in this same period, resulted in very basic changes in the way Leibniz thought about physics and its principles. Leibniz gives an account of this in the "Specimen Dynamicum" (SD) some years later, in 1695. As he characterizes his earlier thought in the SD, the view of the HPN was that body contains only "mathematical notions, size, shape, place, and their change," and that, as a result, the outcome of a collision is determined by the "geometrical composition of conatus alone," resulting in the consequence that the smallest body can move the largest without any resulting loss in speed. And so, Leibniz tells his later readers, he held that "the Wisest Author of things had avoided the consequences that follow *per se* from the bare laws of motion derived from geometry" through the organization of things in the world, the hypothesis of the HPN (SD part I, par. 10, GM VI 241: AG 124).[31] He then continues:

> But after I examined all of this more deeply, I saw what a systematic explanation of things consists in, and noticed that my earlier hypothesis about the notion of body was imperfect. .. . [Bjecause we cannot derive all truths concerning corporeal things from logical and geometrical axioms alone .. ., and because we must appeal to other axioms pertaining to cause and effect, action and passion, in terms of which we can explain the order of things, we must admit something metaphysical, something perceptible by the mind alone over and above that which is purely mathematical and subject to the imagination, and we must add to material mass a certain superior and, so to speak, formal principle. Whether we call this principle form or entelechy or force does not matter, as long as we remember that it can only be explained through the notion of forces. (SD part I, par. ir, GM VI 241: AG ^4-25)

Physical hypotheses about various phenomena will continue to be important for Leibniz, as they were for any orthodox mechanical philosopher of the seventeenth century. But what is important here is that by the end of the 1670s, much of the behavior of bodies that Leibniz attributed to the state of the world now becomes basic to bodies as such; the sort of conservation principle that appears at best as a derivative principle in Leibniz's physics in the 1670s now appears basic to body as we shall develop in more detail below. Leibniz represents this as a move from a geometrical conception of body and its laws to a metaphysical conception. This cannot be exactly right. As we saw earlier, the principle of sufficient reason has an important role to play in the early physics of the TMA and HPN. Furthermore, even in that early physics, body is not "purely mathematical" and composed of "material mass" alone. But it is the case that a number of metaphysical principles, like the equality of cause and effect, now enter into the determination of the ground-level laws of nature in ways that they didn't earlier, and, as a consequence, Leibniz claims, the nature of body cannot be extension or motion, but must be force.

2. THE MATURE PHYSICS: AN OVERVIEW

Leibniz's notes and correspondence in the late 1670s and early 1680s show considerable interest in questions of motion, physics, and, more generally, natural philosophy.'[2] But the foundations of Leibniz's new physics were not publicly revealed until 1686, when Leibniz published his brief but important "Brevis Demonstratio Erroris memorabilis Cartesii et aliorum circa Legem Naturalem" (BD) in the *Acta Eruditorum*In this work, Leibniz presented for the first time in public what he had been telling friends and correspondents in private for some years - that the Cartesian law of the conservation of quantity of motion (size times speed) is false and leads to paradox. We shall discuss this argument in more detail in section 4.3. An enormous controversy followed among the many who still followed Descartes in holding the conservation principle, a controversy that continued well into the 1690s.[34]

While the BD emphasized what is wrong with Descartes' physics, it gave only a hint of what Leibniz intended to replace it with. But shortly after the appearance of that essay, perhaps goaded by the appearance of Isaac Newton's *Piincipia Mathematica* in 1687, Leibniz began to work out the details of his own positive program in physics.[35] Most important from the point of view of the foundations of the new science that Leibniz dubbed "dynamics" is the massive *Dynamica de Potentia et Legibus Naturae corporeae,* written during Leibniz's trip to Italy in 1689-90 with the intention of publication, but unpublished during his lifetime.[36] This work is a systematic treatise on motion and its laws, presenting in a systematic and rigorous fashion the conclusions of the new science. While Leibniz never published the *Dynamica,* he did publish an essay that presents what he takes to be the foundations of the dynamics. This essay was entitled "Specimen Dynamicum" (SD), and was published in the *Acta Eiuditorum* in 169s.[37] Though its title suggests a summary of, or selection from, the earlier work and Leibniz's opening words suggest that the new work will present some hint of what the *Dynamica* contained, little of the highly technical material from the *Dynamica* is found in the SD; instead, what we have is a careful exposition of the metaphysical foundations of the new science, something that is hard to find in the old *Dynamica,* and no less valuable than the more technical physics of the *Dynamica.*

Also important in the writings of this period is the "Tentamen de Motuum Coelestium causis," published in the *Acta Eiuditorum* in 1689. In this essay Leibniz offers an account of the motion of the planets, using a complex scheme of vortices, a more explicitly mechanist alternative to the account in terms of the theory of universal gravitation that Newton presented in his *Piincipia,*[38] While Newton does not deny that there may be an underlying mechanical explanation of the force of gravity he discovered and the motion of the planets that follows from that force on his theory, his *Piincipia* offers no such account. Leibniz's essay, on the other hand, is intended specifically to offer such an account; it is a most visible tribute to the depths of Leibniz's continuing commitment to the mechanist program of a physics grounded in size, shape, and motion.

These by no means exhaust Leibniz's scientific interests in this period, from which numerous other notes and publications date.3? But what is especially interesting is the way in which Leibniz's new program for physics penetrates the more philosophical writings, particularly in the 1680s and 1690s. In Leibniz's mind, as we shall later see in more detail, the new program for physics is intimately linked with his more philosophical programs, and so Leibniz's enthusiasm for his new physics spills over into works like the *Discouise on Metaphysics,* his philosophical correspondence, particularly the letters with Arnauld in the late 1680s, essays like the "Correction of Metaphysics . . ."of 1694, and the "New System" of 1695. Most interesting here is an essay Leibniz published in 1698, "On Nature Itself," which, Leibniz announces in the subtitle, is "on the inherent force and actions of created things, toward confirming and illustrating their dynamics."

It is in the 1680s and 1690s that Leibniz is most actively interested in working out his physics and the metaphysical questions connected with it. His interest in physics by no means disappears in later writings; he continues to discuss his ideas in physics and its foundations with his correspondents, as is shown, for example, by his correspondence with DeVolder, Des Bosses, and, especially, the correspondence he conducted at the very end of his life with Samuel Clarke, who acted as a stand-in for the great Sir Isaac Newton.[40] But by the late 1690s, it is fair to say that Leibniz's basic views on physics and its foundations are well settled. Without ignoring those later writings, I shall try to give an overview of Leibniz's thought on matters of physics in these two crucial decades. Before turning to the details, though, it will be helpful to introduce a distinction implicit in Leibniz's writings about the natural world, a distinction that will help to organize the discussion to follow.

Throughout his mature writings, Leibniz sides with the mechanists against both the philosophy of the schools and against the Newtonian attempt to extend the mechanical philosophy through the introduction of gravity, a force that some Newtonians, if not Newton himself, thought was inexplicable in mechanical terms. But, Leibniz held, the mechanical physics is not fundamental in a very important sense. Leibniz writes in a characteristic passage from the *Discourse on Metaphysics of* 1686:

> Although all the particular phenomena of nature can be explained mathematically or mechanically by those who understand them, nevertheless the general principles of corporeal nature and of mechanics itself are more metaphysical than geometrical, and belong to some indivisible forms or natures as the causes of appearances, rather than to corporeal mass or extension. *(Discourse,* par. 18, G IV 444: AG 51-52)[41]

These "indivisible forms or natures" pertain to corporeal substances, which, as we shall see below, are characterized in the physical writings in terms of the notion of force. This suggests that there are at least two levels in Leibniz's natural philosophy. At the surface, as it were, is the mechanical philosophy, in which everything is explained in terms of the notions of size, shape, and motion, assuming that motion satisfies certain laws. This, I think, is what Leibniz often thought of as physics proper. But below physics proper stands the science that treats force and the metaphysical entities, the corporeal substances to which force, properly speaking, pertains and from which motion and its laws derive. This science is what Leibniz called dynamics.[42] Leibniz clearly thinks that dynamics is closely connected to metaphysics, but the relation between the corporeal substances, characterized in terms of force, and the individual substances, later monads, that dominate his more directly metaphysical writings is obscure, as we shall later see.[43] In the remainder of this essay, I would like to focus on the more straightforward categories of physics and dynamics. The two levels are difficult to separate completely and treat entirely independently. I will begin by discussing the dynamical level in Leibniz's natural philosophy, the notion of force, before turning to the notions of space, shape, and motion that constitute Leibniz's notion of physics proper.

3. FORCE: THE DYNAMICAL LEVEL

3.1 The refutation of the Cartesian doctrine of body

Cartesian physics was still very much alive when Leibniz began to work out his own ideas about physics in the 1670s and 1680s. A reasonable place to begin our account of Leibniz's views on the physical world is with an account of his rejection of the Cartesian doctrine of the nature of body, and his advocacy of a conception of body grounded in the notion of force; in this is grounded his dynamics.

Basic to Descartes and his many followers was the view that the essence of body is extension; bodies, for Descartes, were the objects of geometry made real. As a consequence, Descartes held that all of the bodies' properties are broadly geometrical, including size, shape, position with respect to other bodies, and motion. This was central to Cartesian mechanism; because all there is in body is extension and its modes everything in physics must be explicable in those terms.[44]

Leibniz shared the mechanical philosophy of the Cartesians; for him, too, everything was explicable in terms of size, shape, and motion. But though he shared the physics, he did not share the metaphysics on which Descartes had grounded his mechanism. While bodies may be extended, Leibniz held that this was not their essence.

Leibniz offers a number of interesting arguments against the

Cartesian conception of body from a number of different premises, and leading to a number of different conclusions.

First, there are arguments showing the insufficiency of the notion of extension for defining body. Leibniz argues that extension cannot be the essence of body, as Descartes and his followers claim, because extension is not the sort of thing that *can* constitute the essence of *anything;* it is a relative concept, he claims, and is comprehensible only with respect to some quality or other that is extended (see, e.g., GIV 467; letter to Malebranche, 1693-94?. GI 352; to De Voider, 24 March 13 April 1699, G II 169-70: AG 171-72; G IV 393-94: AG 251; G VI 584: AG 261). Leibniz also offers a somewhat puzzling argument to the effect that insofar as bodies in the real world are actually divided to infinity, strictly speaking they have no shape. Since one cannot have an extended thing that has no shape, extension cannot constitute the essence of body.« These arguments, interesting as they are, lead us away from the Cartesian position, but don't lead clearly toward anything else.

Other arguments, though, give us more insight into Leibniz's own position. One of the most important such arguments is what might be called the aggregate argument. This is the main argument he uses against the mechanist ontology in the letters he wrote to Amauld in the late 1680s. There he focuses on the fact that for most Cartesian mechanists, body is infinitely (or, to use Descartes' phrase, indefinitely) divisible.[46] In writing to Amauld, Leibniz announces: "I hold this basic proposition, differentiated only by the emphasis to be an axiom, namely, that *what is not truly* one *being* is *not truly one* being *either"* (letter to Arnauld, 30 April i687:G II 97: AG 86). So, Leibniz concludes, the ultimate existents in his world must be things that are genuinely one, genuine unities. Thus, Leibniz claims that the reality of aggregates must depend on the reality of the individuals that make up those aggregates: "I do not agree that *there are only aggregates of substances,* and if there are aggregates of substances, there must also be true substances from which all the aggregates result" (letter to Arnauld, 30 April 1687, GII 96: AG 85). Now, Leibniz claims that extended things, at least inanimate extended things, are by their nature aggregates; *any* body, taken by itself is only an aggregate of the parts into which one can divide it (see the discussion in letter to Amauld, 28 November/8 December 1686, GII 76: AG 79). And so, Leibniz concludes:

We must then necessarily come down either to mathematical points of which some authors constitute extension, or to the atoms of Epicurus or Cordemoy (which things you reject along with me), or else we must admit that we do not find any reality in bodies; or finally we must recognize some substances that have a true unity.

(Letter to Arnauld, 30 April 1687, G II 96: AG 85)

That is, for extended bodies to be real, they must ultimately be composed of things that are genuine unities, something that cannot be found in extension alone.[47]

The aggregate argument turns on the fact that in the infinitely divisible bodies of the Cartesians there are no genuine individuals, and thus no reality, properly speaking. Another argument Leibniz gives goes even a step further. In sec. 13 of the important essay "On Nature Itself" (1698), Leibniz presented a general argument intended to show that if the world is full, and full of matter uniform in its nature (both of which follow from the doctrine of body as extension Descartes held), then change is impossible. Leibniz argues:

For if no portion of matter whatsoever were to differ from equal and congruent portions of matter, . . . and furthermore, if one momentary state were to differ from another in virtue of the transportation of equal and interchangeable portions of matter alone, portions of matter in every way identical, then, on account of this perpetual substitution of indistinguishables, it obviously follows that in the corporeal world there can be no way of distinguishing different momentary states from one another. (G IV 513: AG X63—64)

The problem Leibniz has in mind here is not merely epistemological, a matter of our not being able to *tell* whether or not the world is changing (though given our evident experience of change, this would be problem enough for the mechanist); the problem is deeper, that given the common mechanist conceptions of body, it doesn't even make *sense* to talk about same and different with respect to body: "under the assumption of perfect uniformity of matter, one cannot in any way distinguish one place from another, or one bit of matter from another bit of matter in the same place" (GIV 513-14: AG 164).

These arguments establish that bodies must be grounded not in bare geometrical extension but in some sort of unities; genuine individuals. Leibniz's conception of these individuals is further fleshed out in another series of arguments against the Cartesian doctrine of body that emphasize the notions of force and activity.

First, there is a suggestion that the Cartesian view of body is refuted by the very refutation of the Cartesian conservation principle, and that when we substitute the conservation of mv^2 for the Cartesian size times speed, it follows that we must introduce something into body over and above extension. Leibniz writes to Bayle about his new conservation law, shortly after the publication of the BD:

I would like to add a remark of consequence for metaphysics. I have shown that force ought not to be estimated by the product of speed and size, but by the future effect. However, it seems that force or power is something real at present, while the future effect is not. From which it follows *that we must admit in bodies something different from size and speed, at least unless one wants to refuse bodies all power of acting.*

(Letter to Bayle, 9 January 1687, G III 48)

The argument is somewhat obscure, but what Leibniz seems to have in mind is this. For the Cartesian, all there is in body must be geometrical, size and speed. But if the ability to do work is conserved, for example, the ability a body has to raise itself a certain height, then it is not size times speed that is conserved, but size times the square of speed/[8] That is to say that neither size nor speed (nor their product) can represent in a body at a time n the ability that that body has at some future time to do work. But since the body really does have that ability at time *n,* there must be something it has at time n by virtue of which it has that future ability, something that goes beyond its geometrical properties; this is what Leibniz calls force.«

Perhaps more intelligible is another kind of argument Leibniz appeals to, an argument that derives from the claim that Cartesian bodies, the objects of geometry made real, must be completely inert, and indifferent to motion or rest. This argument is used in a wide variety of texts in the late 1680s and throughout the 1690s. Leibniz sketches the argument in the *Discourse on Metaphysics.:*

If there were nothing in bodies but extended mass and nothing in motion but change of place and if everything should and could be deduced solely from these definitions by geometrical necessity, it would follow . . . that, upon contact, the smallest body would impart its own speed to the largest body without losing any of this speed; and we would have to accept a number of such rules which are completely contrary to the formation of a system. (Discourse, par. *21,* G IV 446-47: AG 53-54)[50]

The argument is clear enough. If bodies were just extended, as the Cartesians say, then they would have to obey certain absurd laws of motion; in particular, the smallest body in motion could move the largest body at rest without losing any of its own motion, as in Leibniz's own early physics. But this is absurd, in contradiction both with experience, and with metaphysics, since in a world governed by such a law, the *mv** in a collision could increase or decrease, depending upon circumstances, resulting in violations of the principle of the equivalence of cause and effect. And so Leibniz concludes, there must be something in bodies over and above mere extension, something from which the force of resistance can arise.[51]

This argument is not entirely fair to Descartes and his followers. The laws Leibniz criticizes in this argument are not Descartes', nor do they belong to any of his followers; Descartes himself certainly recognized a kind of resistance in bodies, something that he traced back to God, the ultimate source of motion in the physical world.[52] But his isn't good enough for Leibniz. In 1702, Leibniz writes:

Though in origin [motions] ought to be attributed to God, the general cause of things, however, directly and in particular cases, they ought to be attributed to the force God placed in things. For to say that, in creation, God gave bodies a law for acting means nothing, unless, at the same time, he gave them something by means of which it could happen that the law is followed; otherwise, he himself would always have to look after carrying out the law in an extraordinary way. But indeed, his law is efficacious, and he did render bodies efficacious, that is, he gave them an inherent force.
(G IV 396-97: AG 253-54; cf. SD part I, par. rr, GM VI 241-42: AG r25; "On Nature Itself," G IV 508-09: AG r59-6o; G IV 568: L 583)

But if force is in the bodies themselves, then they cannot be the inert extended things that they are for the Cartesians.

These arguments establish that the bodies of the mechanical philosophy are not things merely extended. Rather, Leibniz argues, they are grounded in genuine unities that are the seat of forces in the world. But to fully understand Leibniz's position here, we must understand what exactly he means by "force." It is to this question that we must turn.

3.2 *Body and force*

The notion of force was important to Leibniz's mature thought from the time of its origins in the late 1670s. It is fair to say that in the early seventeenth century the notion of force had no single definite meaning, nor did it in Leibniz's own earlier writings.[53] But throughout Leibniz's writings in the 1680s and 1690s, it is in the process of becoming a more precise technical term. The notion of force and the distinctions that Leibniz draws among the different kinds of force do not emerge all at once. But by 1695 everything seems to be in place, and Leibniz's ontology of force and its relation to the notions of body and substance receive a tidy and well-organized presentation in the SD.

In the SD and related writings, Leibniz presents a conception of force that involves two important distinctions, the distinction between primitive and derivative forces, and the distinction between active and passive forces. So in all, there are four principal varieties of force - primitive active and passive force, and derivative active and passive force. Leibniz writes:

Active force [which might not inappropriately be called *power* [virtus] as some do] is twofold, that is, either *primitive,* which is inherent in every corporeal substance *per se ... or derivative,* which, resulting from a limitation of primitive force through the collision of bodies with one another, for example, is found in different degrees. Indeed, primitive force (which is nothing but the first entelechy) corresponds to the *soul or substantial form*. . . . Similarly, passive force is also twofold, either primitive or derivative. And indeed, the *primitive* force *of being acted upon* [vis *primitiva patiendi]* or of resisting constitutes that which is called *primary matter* in the schools, if correctly interpreted. This force is that by virtue of which it happens that a body cannot be penetrated by another body, but presents an obstacle to it, and at the same time is endowed with a certain laziness, so to speak, that is, an opposition to motion, nor, further, does it allow itself to be put into motion without somewhat diminishing the force of the body acting on it. As a result, the *derivative force of being acted upon* later shows itself to different degrees in *secondary matter.*

(SD, part I, par. 3, GM IV 236-7: AG 119-20)[54]

Let us begin by examining the notions of active and passive force. Leibniz writes in the SD:

[Active] force is . . . twofold. One force is elementary, which I also call *dead force,* since motion does not yet exist in it, but only a solicitation to motion, as with the ball in the tube[55] or a stone in a sling being held in by a rope. The other is ordinary force, joined with actual motion, which I call *living foice* [vis *viva].* An example of dead force is centrifugal force itself, and also the force of heaviness [vis *gravitatis]* or centripetal force, and the force by which a stretched elastic body begins to restore itself. But when we are dealing with impact, which arises from a heavy body which has already been falling for some time, or from a bow that has already been restoring its shape for some time, or from a similar cause, the force in question is living force, which arises from an infinity of continual impressions of dead force.

(SD, part I, par. 6, GM VI 238: AG i2r-22.)

This suggests that active force is to be connected with velocity and acceleration, more specifically, dead force with acceleration, and living force with actual motion. But though connected, active forces must not be *identified* with motion or acceleration; motion and change in motion (acceleration) are not forces themselves, as we shall later see in sec. 4.2, but the *effects* of forces. Furthermore, the BD argument shows that what is conserved in nature is not size times speed, but size times the square of speed. And so, if what is conserved in motion is force (living force), then force is not to be identified with motion *simpliciter,* since when the motion (velocity or speed) is doubled, the force is quadrupled.

Passive force is something quite different.[56] As the earlier passage quoted from the SD suggests, passive force is connected not with motion, but with the resistance to motion. This resistance is of two sorts.[57] First there is impenetrability, "that by virtue of which it happens that a body cannot be penetrated by another body." But in addition to that there is a kind of passive force by virtue of which bodies actively oppose the motion other bodies try to impose on it in impact, what Leibniz calls "a certain laziness." This resistance is something quite different from the mere tendency bodies have to remain in a given state, a notion basic to the thought of Descartes, Hobbes, and Spinoza. Leibniz writes to the Cartesian De Voider:

I admit that each and every thing remains in its state until there is a reason for change; this is a principle of metaphysical necessity. But it is one thing to retain a state until something changes it, which even something intrinsically indifferent to both states does, and quite another thing, much more significant, for a thing not to be indifferent, but to have a force and, as it were, an inclination to retain its state, and so to resist changing.

(Letter to De Voider, 24 March/3 April *1699·,* G II 170: AG r72)[58]

It is this force of resistance that slows the body in motion colliding with the body at rest, allowing Leibniz to avoid the result that so tainted his own early physics. As with the active forces, Leibniz differentiates passive forces from the behavior in bodies that they cause. In the SD Leibniz is careful to characterize passive force as "that by virtue of which it happens" that bodies have impenetrability and resistance; the passive forces are the causes of this behavior in just the way that the active forces are the causes of motion. Passive force also seems to be the cause (in a somewhat extended sense) of a body's extension. Writing to Arnauld, Leibniz discusses the "primitive passive power [i.e., force]" of a substance as its matter, and claims that "in this sense matter would not be extended or divisible, although it would be the principle of divisibility or that which amounts to it in the substance" (letter to Amauld, 9 October 1687, GII120; see also GIV 394: AG 251). The view seems to be that the extension of a body is just the diffusion of resistance; extension is, properly speaking, a direct consequence of the property bodies have by virtue of which they resist penetration by other bodies.

Let us now turn to the distinction between primitive and derivative forces. In the passage from the SD quoted above, Leibniz characterizes the primitive active force as corresponding to "the soul or substantial form"; the primitive passive force, on the other hand, is characterized as constituting "that which is called *primary matter* in the schools, if correctly interpreted." Form and matter are, of course, terms of art from the Aristotelian account of substance; as noted earlier in characterizing the Aristotelian conception of substance in section 1, form and matter join together to constitute a substance for Aristotle and his followers. And so for Leibniz as well. Leibniz writes in his essay of May 1702:

> Primitive active force, which Aristotle calls first entelechy and one commonly calls the form of a substance, is another natural principle which, together with matter or [primitive] passive force, completes a corporeal substance. This substance, of course, is one *per se,* and not a mere aggregate of many substances, for there is a great difference between an animal, for example, and a flock. (G IV 395: AG 252)

And so, it seems, the primitive forces, active and passive, come together to make up the corporeal substance, the genuine unity that, Leibniz claims, underlies the extended bodies of physics.

Derivative forces, in contrast, are the forces most of interest to the physicist. Leibniz writes in the SD:

Therefore, by derivative force, namely, that by which bodies actually act on one another or are acted upon by one another, I understand .. . only that which is connected to motion (local motion, of course), and which, in turn, tends further to produce local motion. For we acknowledge that all other material phenomena can be explained by local motion.

(SD, pt. I, par. 4, GM VI 237: AG r20)

Derivative force is, furthermore, that in terms of which we can frame the laws of physics. Leibniz writes, again in the SD:

It is to these notions [i.e., the derivative forces] that the laws of action apply, laws which are understood not only through reason, but are also corroborated by sense itself through the phenomena.

(SD, part I, par. 3, GM VI 237: AG r20)

Leibniz uses a number of terms to describe the relation between primitive and derivative forces. In the SD.he talks of derivative force as resulting from "a *limitation* of primitive force through the collision of bodies with one another" (SD, part I, par. 3, GM VI 236: AG 119). In the first draft of the "New System" (ca. 1694) he writes:

[I call form or entelechy] the primitive force in order to distinguish it from the secondary [i.e., derivative force], what one calls moving force, which is a limitation or accidental variation of the primitive force. (G IV 473)

Similarly, he writes to Bernoulli in 1698:

If we conceive of soul or form as the primary activity from whose modification secondary [i.e., derivative] forces arise as shapes arise from the modification of extension, then, I think, we take sufficient account of the intellect. Indeed there can be no active modifications of that which is merely passive in its essence, because modifications limit rather than increase or add.

(Letter to Bernoulli, 17 December 1698, GM III 552: AG 169)

And finally, Leibniz writes in the essay of May 1702 that "active force is twofold, primitive and derivative, that is, either substantial or accidental (G IV 395: AG 252). These passages suggest that derivative forces are to be understood as modes, accidents or the like, modifications of the primitive forces, which are understood as substances, or, better, as constituents of corporeal substances. Primitive active and passive forces, then, are the substantial ground of the derivative active and passive forces, which are their accidents or modes, as shape is an accident or mode of an extended thing.

The picture of the physical world that emerges out of the SD and related writings is quite interesting for the way in which it joins scholasticism with mechanism. At the metaphysical ground are corporeal substances, unities of form and matter, primitive active and passive forces. These, in turn, ground derivative forces, the modes or accidents of these primitive forces, their momentary states that can change as do shapes in an extended substance. The derivative forces, active and passive, in turn, are the immediate cause of motion, resistance, impenetrability, and even extension in bodies, giving rise to the mechanist's world of extended bodies in motion, following certain laws. In this way Leibniz can say, as we have seen, that everything in the world happens mechanically, but that the world of the mechanical philosophers is grounded in something quite different than extended matter and motion, an Aristotelian metaphysics of substantial form and primary matter; it is the dynamics, the science of force that links the underlying Aristotelian metaphysics with the physics of the mechanists. The final form of this doctrine, with its careful distinction between form and matter, primitive and derivative forces, active and passive forces of different varieties may not appear until the mid 1690s; but the basic picture is integral to Leibniz's thought about the physical world from the 1680s on.*»

In section 4 of this essay, we shall turn to the mechanist physics that Leibniz builds on the foundations of the dynamics, but we must first take a turn in the other direction, to the metaphysics, and examine the relation between the apparently Aristotelian metaphysics that seems to underlie the SD and the conception of substance that underlies Leibniz's more familiar metaphysical writings.

3.3 *Dynamics and the metaphysics of substance*

The world of forces Leibniz came to sketch in the SD and related writings is grounded in the active and passive primitive forces he posits, which he interprets as the form and matter of corporeal substance. But, one might ask, what status do these corporeal substances have in Leibniz's complex metaphysics? The answer to this is, unfortunately, not altogether clear. The careful reader can find at least two different strains in Leibniz's writings.[60]

One view is found very prominently in the 1680s and 1690s when Leibniz was most actively working out his physics: it is the corporeal substances of the dynamical writings that form the metaphysical grounding of Leibniz's system. This view falls naturally out of the aggregate argument, discussed in section 3.1, as developed particularly in the correspondence with Arnauld. The point of the argument is to show that extension is not, by itself, sufficient to constitute body, and that underlying the extension there must be genuine substances. These substances are quite clearly the corporeal substances that constitute the foundations of the dynamics. Leibniz is quite clear that the human being is one, both body and soul. He writes:

> Man ... is an entity endowed with a genuine unity conferred on him by his soul, notwithstanding the fact that the mass of his body is divided into organs, vessels, humors, spirits, and that the parts are undoubtedly full of an infinite number of other corporeal substances endowed with their own entelechies.
>
> (Letter to Arnauld, 9 October 1687, G II 120; see also letter to Arnauld, 28 November/8 December 1686, G II 75: AG 78)

Here the body is regarded as a collection of corporeal substances, united by a soul, which gives them true unity. Each of the corporeal substances that make up the body of the human being is itself a body (a collection of smaller corporeal substances), united by its own soul. In general, his view seems to be that all genuine substances are to be understood as living creatures of a sort, on analogy with the human being, unities of soul and body, and that the world is filled with an infinity of such genuine substances, nested in one another to infinity. Leibniz writes to Arnauld:

> I am very far removed from the belief that animate bodies are only a small part of the others. For I believe rather that everything is full of animate bodies, and to my mind there are incomparably more souls than there are atoms for M. Cordemoy, who makes a finite number of them, whereas I maintain that the number of souls or at least of forms is quite infinite, and that since matter is endlessly divisible, one cannot fix on a part so small that there are no animate bodies within, or at least bodies endowed with a basic entelechy or (if you permit one to use the word "life" so generally) with a vital principle, that is to say corporeal substances, about which it may be said in general of them all that they are living.
>
> (Letter to Arnauld, 9 October 1687, GII118)

These corporeal substances, conceived on analogy with animals, are, I believe, the basic constituents of the world for Leibniz. While he does recognize souls and forms here, he is quite unsure whether or not they deserve the status of substances. In a very interesting document from March 1690, comments on some remarks by Michel Angelo Fardella, Leibniz remarks:

The soul, properly and accurately speaking, is not a substance, but a substantial form, or the primitive form existing in substances, the first act, the first active faculty. ("Notes on Fardella, March 1690," FC 322: AG ros)

And even if the soul or form were a substance, Leibniz is clear that it never actually exists without being attached to a body (see, e.g., GIV 395-96: AG 252-53). Particularly significant are Leibniz's first uses of the term "monad," which enters Leibniz's philosophical vocabulary in the late 1690s. Writing to Johann Bernoulli in September 1698, Leibniz notes:

What I call a complete monad or individual substance is not so much the soul, as it is the animal itself, or something analogous to it, endowed with a soul or form and an organic body.
(Letter to Johann Bernoulli, 20/30 September 1698, GM III 542: AG 168)

And so, Leibniz wrote in that same letter:

You ask me to divide for you a portion of mass into the substances of which it is composed. I respond, there are as many individual substances in it as there are animals or living things or things analogous to them.
(ibid., GM III 542: AG 167)[61]

While the world of physics may be grounded in such substances, tiny animals, not every body is animate, of course. But, Leibniz argues, the inanimate bodies of physics are made up of such substances. Bodies emerge in this picture looking something like a pile of stones, or, better, a flock of sheep or a pool of wriggling fish, to use comparisons Leibniz often used. In this view, bodies, inanimate bodies at least, are phenomenal insofar as it is *we* who put the pieces (animate substances) together to form an individual. As Leibniz explains it to Arnauld:

Our mind notices or conceives some true substances which have certain modes; these modes involve relations to other substances, so the mind takes the occasion to join them together in thought and to make one name account for all these things together. This is useful for reasoning, but we must now allow ourselves to be misled into making substances or true beings of them. (Letter to Arnauld, 30 April 1687, GII101: AG 89)

In this view, it is relatively easy to fit the ontology of the SD and other dynamical writings directly into Leibniz's other metaphysical writings. In this view, the active and passive primitive forces of the dynamics correspond reasonably well to the form and matter of the metaphysical writings.[62] The derivative forces, then, emerge as modes of corporeal substance, and their reality in inanimate bodies is grounded in the corporeal substances that make them up.[6']

But this isn't Leibniz's only metaphysical conception of the world, and it isn't the only way he conceives of the metaphysical foundations of his dynamics. Better known is the metaphysics of the *Monadology,* where Leibniz's individual substances, what he comes to call monads, are conceived not on the model of animals but on the model of Cartesian souls (see letter to De Voider, 1699, G II 194: L 522). While traces of this position can be found in virtually every period of Leibniz's mature writings, it is what seems to dominate after 1704 or 1705. In late writings, such as the *Monadology,* Leibniz still holds that the physical world is made up of organisms, and that these organisms are everywhere in apparently lifeless matter, as in the correspondence with Arnauld (see, e.g., *Monadology,* pars. 63ff., G VI 617-18: AG 221-22). However, he holds that what is ultimately real are the mind-like simple substances, and, in general, he holds that the organisms that populate the world are not themselves substances, in the proper sense of the word. The inanimate bodies physics usually treats have a somewhat complex structure, then, and are, in a sense, doubly phenomenal. First of all, they are made up of an infinity of living things, rudimentary organisms. But these organisms are, in turn, phenomenal, aggregates of genuine substances, monads and are not themselves fully real (see, e.g., letters to De Voider, 30 June 1704 G II 268:AG 178-79, 1704 or 1705, G II 275:AG I8I; "Antibarbarus Physicus," G VII 344: AG 319-20).[64]

Where do the forces of the SD fit into this metaphysical picture? One answer emerges out of what Leibniz wrote to De Voider in 1704 or 1705:

I don't really eliminate body, but reduce it to what it is. For I show that corporeal mass, which is thought to have something over and above simple substances, is not a substance, but a phenomenon resulting from simple substances, which along have unity and absolute reality. I relegate derivative forces to the phenomena, but I think that it is obvious that primitive forces can be nothing but the internal strivings of simple substances, strivings by means of which they pass from perception to perception in accordance with a fixed law of their nature.

(Letter to De Voider, r704 or 1705, G II 275: AG r8i)[6s]

Similarly Leibniz wrote to Des Bosses in 1706:

From a multiplicity of monads results secondary matter, alone with derivative forces, actions, passions, which are only entities through aggregation, and therefore semi-mental, like the rainbow and other well-founded phenomena. (Letter to Des Bosses, ri March 1706, GII 306)[66]

This suggests the following picture. The primitive forces, active and passive, now pertain not to corporeal substances, but to the monads; they are now identified with what Leibniz calls appetition, the activity in things by virtue of which a monad passes from one internal state to another. Derivative forces, on the other hand, are relegated to the phenomena. These forces, those that are the direct cause of motion and thus most of interest to the physicist, pertain now to bodies and bodies alone. While grounded in something that is real - the monads or simple substances - they belong to aggregates of monads alone, and thus are irreducibly phenomenal.

But this may not have been Leibniz's considered opinion. The question of the possibility of a genuine composite substance (like the corporeal substances of the correspondence with Arnauld) is one of the main themes of the correspondence with Des Bosses; in these letters Leibniz is trying to figure what would be required for there to be such things in his world of monads.[67] In an appendix to the letter to Des Bosses from 19 August 1715, Leibniz presented a diagrammatic representation of his views on unity and beings by aggregation (GII 506: L 617). He begins with a distinction between things that are genuine individuals, and beings by aggregation. Now, in this scheme, derivative force (here derivative power) appears twice, once as a modification of a composite substance, and once as a "semiaccident," the modification of a "semisubstance," a being by aggregation, which, Leibniz says, derives "from the modifications of [genuine] substances." But primitive active and passive force (here, primitive active and passive power) appears only once in the diagram, in the characterization of a composite substance, which, Leibniz says, "consists in primitive active and passive power, that is, it consists in primary matter, i.e. the principle of resistance, and in substantial form, i.e. the principle of impetus."[68] Interestingly enough, it does not appear on the other side of the chart, in the characterization of semisubstances. In this reading, if there are no genuine composite (corporeal) substances in the world, then all derivative force must be phenomenal. But in that situation, there would be no primitive forces at all in the world, it would seem.[6»]

In the end, then, it is not clear exactly how the world of the dynamics, primitive and derivative, active and passive forces is supposed to fit into Leibniz's larger metaphysical picture. But then, what uncertainty there is derives from Leibniz's own uncertainties about the details of that metaphysics, as it evolved from the 1680s to the end of his life.

3.4 Dynamics and the refutation of occasionalism

Leibniz's dynamics was central to his program for physics. In the next section we shall see how his account of force is connected with his conception of the world of the mechanical philosophy and the mathematical laws that govern it. But the dynamics was also connected with an important theme in Leibniz's metaphysics, the rejection of occasionalism.

The doctrine of occasionalism was central to seventeenth-century metaphysics, particularly among the Cartesians. In this widely held view, the changes that one body appears to cause in another upon impact, the changes that a body can cause in a mind in producing a sensation, or a mind can cause in a body in producing a voluntary action are all due directly to God, moving bodies or producing sensations in minds on the occasion of other appropriate events. The doctrine of occasionalism is sometimes presented as having been primarily a solution to the problem of mind/body interaction; since it is inconceivable how minds and bodies can interact, it is argued, seventeenth century philosophers held that it is God who connects the motion of the sensory organs with the sensation in the mind, and the volition in the mind with the voluntary motion of the body. But in reality, the motivation for the doctrine among most seventeenth-century philosophers is somewhat different.[70]

For many of Descartes' later followers, what is central to the doctrine of occasionalism is the denial of the efficacy of finite causes simply by virtue of their finitude. Clerselier, for example, argues for occasionalism by first establishing that only an incorporeal substance can cause motion in body. But, he claims, only an infinite substance, like God, can imprint new motion in the world "because the infinite distance there is between nothingness and being can only be surmounted by a power which is actually infinite."[71] Cordemoy argues similarly. Like Clerselier, he argues that only an incorporeal substance can be the cause of motion in a body, and that this incorporeal substance can only be infinite; he concludes by saying that "our weakness informs us that it is not our mind which makes [a body] move," and so he concludes that what imparts motion to bodies and conserves it can only be "another Mind, to which nothing is lacking, [which] does it [i.e., causes motion] through its will."[72] And finally, the infinitude of God is crucial to the main argument that Malebranche offers for occasionalism in his central work, *De la recherche de la vérité.* The title of the chapter in which Malebranche presents his main arguments for the doctrine is "The most dangerous error in the philosophy of the ancients."[75] And the most dangerous error he is referring to is their belief that finite things can be genuine cause of the effects that they appear to produce, an error that, Malebranche claims, causes people to love and fear things other than God in the belief that they are the genuine causes of their happiness or unhappiness.[74] But why is it an error to believe that finite things can be genuine causes? Malebranche argues as follows:

> As I understand it, a true cause is one in which the mind perceives a necessary connection between the cause and its effect. Now, it is only in an infinitely perfect being that one perceives a necessary connection between its will and its effects. Thus God is the only true cause, and only he truly has the power to move bodies. I further say that it is not conceivable that God would communicate to men or angels the power he has to move bodies.[7S]

For these occasionalists, then, God must be the cause of motion in the world because only an infinite substance can be a genuine cause of anything at all.

Leibniz's dynamics is intended as a direct challenge to occasionalism,· rather than inert extended bodies shuffled about by a God who is the only source of genuine activity in the world, Leibniz posits genuinely active bodies, bodies that are the source of their own activity, bodies, in short, that genuinely embody forces.

Leibniz offers a number of arguments to this conclusion.[76] One of them was discussed in section 3.1, in connection with the refutation of the Cartesian conception of body as extension. There, Leibniz argues that God gave bodies forces, that is, the ability to act because otherwise he would always have to carry out his commands himself. More generally, Leibniz argues that occasionalism involves a perpetual miracle insofar as on that doctrine, God must carry out his own commands. Leibniz writes to Arnauld:

> Properly speaking, God performs a miracle when he does something that surpasses the forces he has given to creatures and conserves in them.... Thus. . . we must say . . . that if continuing motion exceeds the force of bodies, then the continuation of the motion is a true miracle. But I believe that corporeal substance has the ability *[force]* to continue its changes in accordance with the laws God put into its nature and conserves there.
>
> (Letter to Arnauld, 30 April 1687, G II 93: AG 83)

Leibniz also argues that placing force and activity in bodies is necessary for them to exist as genuine entities, independent of God. And so, he writes in section 8 of "On Nature Itself" (1698):

> The very substance of things consists in a force for acting and being acted upon. From this it follows that persisting things cannot be produced if no force lasting through time can be imprinted upon them by the divine power. Were that so, it would follow that no created substance, no soul would remain numerically the same, and thus nothing would be conserved by God, and consequently everything would merely be certain vanishing or unstable modifications and phantasms, so to speak, of one permanent divine substance. Or, what comes to the same thing, God would be the very nature or substance of all things, a sort of doctrine of ill repute which a recent writer, subtle indeed, though profane, either introduced to the world or revived.
>
> (G IV 508-9: AG 159-60; cf. G IV 396-97: AG 253-54; G IV 567-68: L 583; SD part I, par. 12, GM 242: AG 125)

The argument is obscure, to be sure. But Leibniz is attempting to argue here that unless we follow him away from the occasionalist and toward the dynamical conception of body that he is arguing for, we will find ourselves in Spinoza's camp, where everything exists only as a mode of God, a doctrine he regarded as both false and dangerous.

It is certainly too much to say that Leibniz's physics constitutes a "scientific" refutation of the doctrine of occasionalism; though connected with his dynamics, the arguments against occasionalism have a definite metaphysical flavor. But it is true that the dynamical world of primitive and derivative forces is deeply intertwined with a central aspect of Leibniz's metaphysical program, returning to the world the activity that the Cartesians had improperly removed.

4. MECHANIST PHYSICS: SPACE, MOTION, AND THE LAWS OF MOTION

In the previous section, we examined Leibniz's conception of force, that which underlies the reality of the world for Leibniz. Now we must turn to the physics proper, the mechanist account of the world of extended bodies moving in space that Leibniz grounds in his dynamics. We begin with an account of space and motion, the basic notions in this mechanistic physics, before turning to Leibniz's account of the laws of motion.

4.1 Space and void

The question as to what space is, and whether a vacuum and empty space is possible, is one of the most vexed questions in early modern science. A full history of those notions as treated in thinkers before Leibniz is impossible in the context of this essay.[77] Briefly, coming into the seventeenth century, there are at least two important strains of thought. For Aristotle and his followers, the notion of space independent of body is incoherent; though certain theological concessions had to be made to accommodate divine freedom - God's ability to move the world as a whole if he so chose - what was basic was body, and space was an abstraction from what really was. For the ancient atomists whose doctrines were being actively revived in the early seventeenth century, and for critics of Aristotelianism, space was a something of a sort, something that had a real existence outside of body, and which could exist without body.[78] This same debate continued into the seventeenth century. Descartes and his followers pursued what was basically an Aristotelian line, denying the independent reality of space and the possibility of a vacuum.[79] Others, including the atomist Pierre Gassendi and Blaise Pascal, bolstered by what they interpreted as new experimental evidence, argued for a space that could exist independently of body, both empty and full.[80] The most formidable adherent of this latter view in the seventeenth century was Sir Isaac Newton. Newton argued for a conception of space that was radically independent of the bodies that it may or may not contain. While he recognized that we normally understand space in terms of the sensible bodies that occupy it, in his *Piincipia* of 1687 he argued that physics requires what he called absolute space:

Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces, which our senses determine by its position to bodies, and which is vulgarly taken for immovable space. . . . Because the parts of [absolute] space cannot be seen or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. . . . But in philosophical disquisitions we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them.[81]

In the second edition of 1713, Newton went so far as to identify this absolute space with God himself:

He endures forever, and is everywhere present, and by existing always and everywhere, he constitutes duration and space.... He is omnipresent not only virtually, but also substantially; for virtue cannot subsist without substance. In him are all things contained and moved.[81]

For Newton, then, space is something quite real, something quite independent of the bodies that exist in it.[8']

Leibniz was interested in the notion of space from his earliest writings. Though there is a strong suggestion in some of his earlier writings that he thought of space as something distinct from body[84], in his mature writings he quite clearly denies the independent reality of space, particularly in opposition to the specific form that that doctrine was given in Newton's writings. In a typical passage Leibniz wrote in 1695, the same year as the SD, a reply to Foucher's objections to the "New System" he holds:

Extension or space and the surfaces, lines, and points one can conceive in it are only relations of order or orders of coexistence, both for the actually existing thing and for the possible thing one can put in its place.

(G IV 491: AG 146)

Leibniz explains this at somewhat greater length in his responses to Samuel Clarke, part of the important correspondence between the two at the very end of Leibniz's life, where Leibniz's views are contrasted with those of his great rival, Newton. Leibniz writes:

> The author [i.e., Clarke] contends that space does not depend upon the situation of bodies. I answer: It is true, it does not depend upon such or such a situation of bodies, but it is that order which renders bodies capable of being situated, and by which they have a situation among themselves when they exist together, as time is that order with respect to their successive position. But if there were no creatures, space and time would only be in the ideas of God. (Fourth letter to Clarke, par. 41, G VII 376-77: AG 331)[85]

As was the case with extension, discussed in section 3.1, space is just the order of things, and presupposes the existence of things to be ordered, bodies, ultimately substances, which are the only things that are real in the proper sense for Leibniz. And so, Leibniz holds, space would not exist were there not bodies and the substances which underlie them; as he wrote in an untitled essay from 1689, "space without matter is something imaginary" (C 590: AG 91).

In addition to the general argument against Newton from his own definition of space, Leibniz offers another kind of argument. Responding to Clarke, Leibniz writes:

> I say, then, that if space were an absolute being, something would happen for which it would be impossible that there should be a sufficient reason-which is against my axiom. And I can prove it thus. Space is something absolutely uniform, and without the things placed in it, one point of space absolutely does not differ in anything from another point of space. But, from hence it follows (supposing space to be something in itself, besides the order of bodies among themselves) that it is impossible there should be a reason why God, preserving the same situations of bodies among themselves, should have placed them in space after one certain particular manner and not otherwise - why everything was not placed the quite contrary way, for instance, by changing east into west. But if space is nothing else but this order or relation, and is nothing at all without bodies but the possibility of placing them, then those two states, the one such as it is now, the other supposed to be quite the contrary way, would not at all differ from one another. Their difference therefore is only to be found in our chimerical supposition of the reality of space in itself.
>
> (Third letter to Clarke, par. 5, G VII 363-64: AG 325)

If Newton is right, Leibniz argues, then there is a real difference between our world, as it is, and another world in which the relations between things are the same, but east and west are reversed, for example. But since Newton's absolute space is completely uniform, and one region interchangeable with every other, there can be no reason for God to prefer one configuration to another. And so, if there is absolute space as Newton supposes, then in creating a world in space, God must violate the Principle of Sufficient Reason. Leibniz's conclusion is that such a space cannot, therefore, exist. Leibniz supplements this argument with another. Suppose God were to reverse everything in the universe, as he could if Newton were right. Then we would have a new state of the universe, distinct from the original one, but entirely indistinguishable from it. Such an action on God's part would, thus, be "a change without any change," and God would have acted without doing anything, something Leibniz finds absurd (Fourth letter to Clarke, par. 13, G VII 373: AG 328-29).[86]

Though he agrees with Descartes and the Cartesian tradition that space is not something independent of the bodies that occupy it, Leibniz takes a position on the void that differs from that of the Cartesians in an interesting way. For Descartes, the essence of body is extension, of course. And, he reasons, since there can be no accident without a subject in which it can inhere, whenever there is extension, there must be extended substance, that is, body. From this it follows that where there are no bodies, there can be no space. Furthermore, he concludes, there can be no vacuum, no space (region of extension) that lacks body.[87] Sometimes Leibniz expresses views on the void very similar to those Descartes held. Leibniz asks Clarke, for example:

> If space is a property or attribute, it must be the property of some substance. But of what substance will that bounded space be an affect or property, which the persons I am arguing with suppose to be between two bodies? (Fourth letter to Clarke, par. 8, G VII 372: AG 328; cf fifth letter, par. 48, G VII 402: AG 339)[88]

But elsewhere he takes a different view. As discussed above in section 3.1, extension for Leibniz must be the extension of some quality or other, and cannot constitute the essence of body or anything else. Since extension is a relative notion, and presupposes something that is extended, Leibniz does grant that it is possible to conceive of an extension that is not the extension of force that constitutes body.[89] But while an extended space without body is thus possible for Leibniz in a way in which it isn't for Descartes, it raises other problems. One problem is put succinctly in the "First Truths" paper of 1689:

There is no vacuum. For the different parts of empty space would then be perfectly similar and mutually congruent and could not be distinguished from one another. And so they would differ in number alone, which is absurd. (C *521-22:* AG 33)[90]

Thus, Leibniz argues, the principle of the identity of indiscernibles argues against empty space. Elsewhere, he appeals to the principle of plenitude. Writing to Johann Bernoulli on 13/23 January 1699, he argues:

I don't say that the vacuum, the atom, and other things of this sort are impossible, but only that they are not in agreement with divine wisdom. .. . From an infinity of possibles, God chose, in accordance with his wisdom, that which is most appropriate. However, it is obvious that the vacuum . . . leaves sterile and uncultivated places, places in which something additional could have been produced, while preserving everything else. For such places to remain contradicts wisdom. (GM III 565: AG 170-71)[91]

And finally, Leibniz argues in the letters to Clarke that were there empty spaces in the world, then there would be a violation of the Principle of Sufficient Reason, his master principle. For, Leibniz asserts, "it is impossible there should be any principle to determine what proportion of matter there ought to be, out of all the possible degrees from a plenum to a void, or from a void to a plenum" (Fourth letter to Clarke, G VII 378: AG 332). For Leibniz's God it must thus be all or nothing, and since there is something, it must be all.

4.2 Motion

"If motion ... is something real," Leibniz wrote to Huygens in June of 1694, "it must have a *subject"* (Letter to Huygens, 12/22 June 1694, GM II 184: AG 308). But, as Leibniz had explained to Arnauld some years earlier, this is precisely what motion as commonly understood lacks:

Motion, insofar as it is only a modification of extension and a change of neighborhood [i.e., as Descartes defined it] contains something imaginary, so that one doesn't know how to determine to which among the subjects changing it belongs. (Letter to Arnauld, 30 April 1687, G II 98: AG 86)

The problem that Leibniz is pointing out here is twofold. One problem simply derives from the widely held view that motion, taken by itself, is just the change of spatial relations among various bodies. If this is all that motion is, strictly speaking, then in the case where bodies *A* and *B* are in motion with respect to one another, we are free to consider *A* at rest and *B* in motion or *B* at rest and *A* in motion. "Motion, in all mathematical rigor, is nothing but a change in the positions of bodies with respect to one another," Leibniz wrote in an untitled essay in 1689, "and so, motion is not something absolute, but consists in a relation" (C 590: AG 91). This observation is, of course, not unique to Leibniz, nor is it particularly deep. But Leibniz also holds a deeper and more characteristically Leibnizian view on the matter. Now, motion might be relative in this first, weak sense, and yet one might claim that it is possible to perform an experiment to determine whether it is really *A* or really *B* that is in motion. The most celebrated argument of this sort is Newton's bucket experiment. In his *Principia,* Newton argued that the way the water climbs the sides of a twirling bucket shows that it is the bucket that is moving in a universe at rest, and not the universe twirling around a resting bucket of water.»[2] And so Newton distinguished between relative motion - motion with respect to an arbitrarily chosen rest point, and absolute motion - motion with respect to absolute space." Leibniz knew of Newton's claim, and just as he rejected absolute space, he rejected Newton's absolute motion. Leibniz wrote to Huygens that:

Mr. Newton recognized the equivalence of hypotheses in the case of rectilinear motions. But with respect to circular motions, he believes that the effort that circulating bodies make to recede from the center or from the axis of circulation allows us to know their absolute motion. But I have reasons that make me believe that nothing disrupts the general law of equivalence.

(GM II184-85: AG 308)9+

Leibniz's arguments are difficult and obscure.»' But the basic idea seems to have been this: everyone grants the equivalence of hypotheses for rectilinear motion, that is, we cannot perform any experiments that will allow us to tell whether we are in uniform rectilinear motion or at rest. But, Leibniz seems to have reasoned, in the billiard-ball world of the mechanical philosophy, all curvilinear and accelerated motion is made up of (very short) segments of uniform rectilinear motion, the direction or speed of which is changed by collision with other bodies. And insofar as he thought that we cannot distinguish between a uniformly moving *A* colliding with a resting *B,* and a moving *B* colliding with a resting *A,* he seems to have thought that in the real, mechanical world, at least, the equivalence of hypotheses should hold for curvilinear and accelerated motions as much as it does for uniform rectilinear motions. And so he thought that he could give a demonstration that *no* experiments could allow one to distinguish any frame from any other and establish that the one is the true rest frame and the other isn't; this is what he calls the doctrine of the equivalence of hypotheses, stated (and proved) as proposition 19 of part II, section 3 of the *Dynamica* (GM VI 507-8).[96] And so, according to Leibniz's doctrine, not even an angel could discern whether Copernicus is right in holding that the Earth moves, or Ptolemy and Tycho are right in preferring a moving sun. In an interesting piece, written, significantly enough in 1689, during his year in Italy, where the memory of the condemnation of Galileo was still very much alive, Leibniz wrote:

> And whether the bodies are moving freely or colliding with one another, it is a wonderful law of nature that no eye, wherever in matter it might be placed, has a sure criterion for telling from the phenomena where there is motion, how much motion there is and of what sort it is, or *even whether God moves everything around it, or whether he moves that very eye itself.* (C 590: AG 91)[97]

Nothing in the world of physics taken strictly, that is, nothing in the mechanist world of size, shape, and motion can determine whether a given body is in motion or at rest, *mathematico rigore.* And so, Leibniz argues, motion so understood lacks a determinate subject, and lacking a subject, cannot itself really be a constituent of the world. Behind this view, of course, is a metaphysical assumption or two. Leibniz finds it absolutely unintelligible that there could be a property that is not really a property of some one thing, a property that is *irreducibly* relational. What exactly this means is not altogether clear.[98] But, Leibniz inferred, if motion is to be real, it must be grounded in something that is not mere relation, something that is a real property of real things.

Though Leibniz tried a number of solutions,[99] the one he finally settled on was *force:* "One cannot really . . . say to which subject motion belongs, and thus there is nothing real in motion except force and the power *[potentia}* things are endowed with," Leibniz wrote in a characteristic passage from 1683 (VE II 294; cf. *Discourse,* par. 18, G IV 444: AG si; SD, part II, par. 2, GM VI 247-48: AG 130-1; GIV 369: L 393; G IV 400: AG 256; GIV 523: L 496; VE III 481, 488, 495). The ontology of force we discussed in section 3 gives Leibniz a way of grounding the reality of motion. Though motion or rest taken narrowly, the change of position or the lack thereof, cannot be attributed to individual bodies in a nonarbitrary way, Leibniz claims that there is a real fact of the matter about the force that is the cause of the motion we see, which really can be said to pertain to one body or another. As Leibniz wrote in the *Discourse on Metaphysics* (1686):

> Motion ... is not a thing entirely real. . .. But force or the proximate cause of these changes is something more real, and there are sufficient grounds to attribute it to one body rather than to another. Furthermore, it is only in this way that we can know to which body the motion belongs.
>
> *(Discourse,* par. 18, G IV 444: AG 51)

Though motion understood as change of place is relative, strictly speaking, the appeal beyond the world of extension and its changes to force can break that relativity, Leibniz seems to think, and allow us to talk intelligibly about the *cause* of motion as pertaining to one body rather than another. Motion so grounded can enter the world of physics.

Leibniz's view on motion raises an interesting question, though. Motion is completely relative, and by the doctrine of the equivalence of hypotheses, there are no physical marks to distinguish real motion from apparent; every frame of reference is as good as every other, at least from the point of view of physics proper, that is, if we limit ourselves to the consideration of extended bodies in motion.[100] But, Leibniz argues, underlying motion there must be force, the cause of motion, something that goes beyond the mechanist's world of extension and its modes, something that really pertains to one body rather than another. There is, in this sense, a correct frame for determining motion, the frame in which the motions observed are the effects of real underlying forces which are their causes. *But such a frame could never be identified.* Motion has a foundation, in a sense, but one that makes no real (or apparent) difference in the world of physics; in this way the theory of motion would seem to float free of its foundations in the notion of force.[101]

The fact that we cannot link observed motions to some particular underlying forces should not, by itself, undermine Leibniz's project; Leibniz hadn't intended that force should ground physics in that crude and direct way, I think. What force explains is that the attribution of motion to the world makes sense *at all.* For Leibniz, all real properties of things in the world ultimately reside in genuine individuals. If that is the case, it is evident why mere motion, the mere change of place, just won't do; for it to be intelligible that there is motion at all, there must be something nonrelativistic, something that is an absolute and nonarbitrary property of some individual thing, that is the cause and ground of motion. This is where force comes in. The present state of the world must have a ground in reality, in *some* configuration of forces; *something* must be there, though Leibniz cannot say *what specifically.* Nor does it matter *which* of the infinity of possible configurations of force there are in the world from the point of view of physics; it is only important that there is some one such configuration.

But the appeal to force grounds more than just the reality of motion: it grounds its laws as well. Despite the fact that we cannot determine where the real causes of motion lie in nature, these forces have a crucial role to play in the derivation of Leibniz's laws of motion. This is what we shall see in the following section.

4.3 The laws of motion

In discussing Leibniz's views on the laws of motion, it will be useful to begin where Leibniz himself began, with the critique of others, particularly Descartes.

Let us begin with the Cartesian conservation principle. Basic to Descartes' physics was the principle of the conservation of quantity of motion. According to Descartes, God sustains the universe from moment to moment and, in doing so, preserves the same quantity of motion in the world as a whole, as measured by the size times the speed of each of the bodies in the world.[102] While not without challenge, it was still held by many in the 1670s, '80s, and '90s. It was the Cartesian conservation principle that Leibniz had to confront - and refute-in the late 1670s when formulating his own physics, and it was Leibniz's published critique of the Cartesian conservation principle in the BD of 1686 that raised one of the most visible public controversies in Leibniz's career, as Cartesians came out of the woodwork to defend what many took as the foundation of their physics. Leibniz was not the first to attack Descartes' conservation principle, and the specifics of his arguments owe much to others, particularly Huygens.[10^] But the liveliness of the exchanges that followed the BD suggests that Leibniz's point was still news to many. This controversy, the so-called *vis viva* (living force) controversy, resulted in numerous refinements and variants on the original argument, as formulated in the late 1670s and published in 1686.[104] But leaving all details aside, the arguments Leibniz developed in this connection sort themselves out into two groups, *a priori,* and *a posteriori.*

Let us begin with the *a posteriori* arguments, which likely date back as early as 1676. This group of arguments shares a common strategy and a number of common assumptions to argue to a number of interconnected conclusions. The basic idea behind these arguments is that bodies in motion have an ability to do work by virtue of being in motion; this is the sensible effect of what Leibniz came to call their living force (*vis viva).* This ability to do work can be compared in different bodies by comparing the actual work they accomplish in consuming that force. What Leibniz chooses to look at is the height to which a body in uniform horizontal motion could raise itself when that horizontal motion is turned to the vertical and consumed in ascent; the height to which a body with a given speed can raise itself from the horizontal is a measure of the force it has by virtue of having that motion, Leibniz argues.[10*] Of course, by the equivalence of hypotheses (see section 4.2) we cannot know where the real force is in the world, whether the body moving on a horizontal surface has the force, or whether it is the horizontal surface that does, for instance. But by the same principle of the equivalence of hypotheses, we are also free to attribute the force to the horizontally moving body, if we choose; the laws of physics will come out the same. Certain assumptions, then, allow Leibniz to draw his conclusions. Most basic is the principle of the equality of cause and effect, the principle that "the whole effect has the same power as its full cause, so that one cannot obtain perpetual motion without violating the order of things through an increase in the power of the effect beyond that of its cause" (*Dynamica,* specimen praeliminare, GM VI 287: AG 106).[106] This metaphysical principle, whose significance Leibniz first seems to have realized in 1676 at the time when he first began to move away from his early system, is central to his derivation of the laws of motion. In the *a posteriori* arguments we are examining, it is used to establish that force, the ability to do work, must be conserved in a closed system, and that the speed a heavy body in free fall acquires in falling a distance *d* is sufficient to raise it to that same distance *d*. In addition to the principle of the equality of cause and effect, in the *a posteriori* arguments Leibniz assumes the Galilean law of free fall, that the speed a heavy body falls is proportional to the square root of the distance fallen, that is, that the distance fallen is proportional to the square of the velocity acquired through free fall. This assumption is, of course, *a posteriori.*

These assumptions allow Leibniz to establish that: (1) force (understood as the ability to do work) is not the same as the quantity of motion of the Cartesians; (2) the quantity of motion of the Cartesians is not conserved in the universe,· and (3) what is conserved is mv^1. That force and quantity of motion are different follows out directly from the assumptions Leibniz makes. Consider two bodies; let *A* be one unit in size, and *B* be four. Now, Leibniz reasons, it takes exactly as much work to raise *A* four feet as it does to raise *B* one foot, since one can regard the larger body *B* as being made up of four smaller bodies, each identical to *A,* and each of which is being raised one foot. (See figure 1.) And so, when *A* and *B* fall through those respective distances, and their speeds converted to the horizontal, they should have exactly the same force, that is, ability to do work, for by the principle of the equality of cause and effect, the velocity that *A* and *B* acquire in falling is sufficient to raise those bodies to their original heights, and we have assumed that it takes as much work to raise *A* four feet as it does to raise *B* one. Now, Leibniz argues, when *A* falls, by the Galilean law of free fall it will acquire two degrees of speed, while *B* acquires one. But if that is the case, then after the fall, *A* will have two units of quantity of motion while *B* will have four. So, since *A* and *B* have the same ability to do work (force), it follows that force and quantity of motion cannot be the same.[107] As noted above, it follows directly from the principle of the equality of cause and effect that force, the ability to do work must be

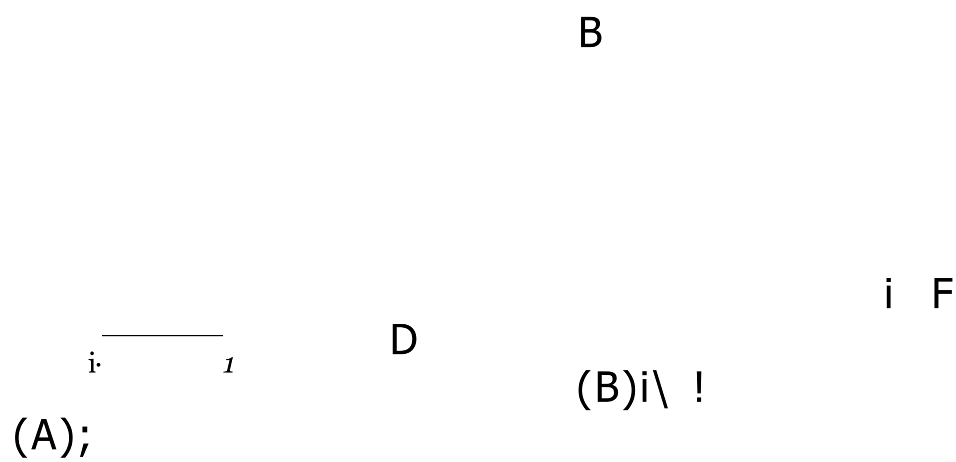

Figure i

conserved in the universe as a whole.[108] That Cartesian quantity of motion is not conserved then follows directly from the conservation of force together with the conclusion that force and quantity of motion are distinct and different.[10'] But the result can also be established directly from the principle of the equality of cause and effect. For, Leibniz can show, if it is the Cartesian's quantity of motion that is conserved, one could build a perpetual motion machine, a machine that would create the ability to do work out of nothing at all, in obvious violation of the the principle of the equality of cause and effect.[110] That mv^1 is the correct measure of force, and thus that it is mv^1 that is conserved in the world can also be established using a variant of this argument. Consider bodies *A* and *B* as above. It is evident that in the case at hand, while *A* and *B* have different quantities of motion, their size times the square of their speeds will be equal. It is easy to generalize this, and show that *whenever* they have equal force, the size times the square of their speed will be equal, and that whenever this is violated, the ability to do work will either be gained or lost, in violation of the principle of the equality of cause and effect (see, e.g., SD, part I, par. 16, GM VI 244-45: AG 128). Similarly, one can show that a perpetual motion machine can always be constructed unless it is mv^1 that is conserved.

But as striking as the *a posteriori* argument is, it has an obvious imperfection. Insofar as it depends on the behavior of heavy bodies in free fall, it depends on certain contingent features of our world that have nothing to do with the basic laws of physics. This sort of criticism is particularly problematic for Leibniz and many of his contemporaries, who believed that gravity derived from the particular configuration of etherial vortices that surround the earth; were the vortices different, the law of free fall might also be altogether different, resulting in a different quantity conserved, it would appear.[111] In response to such a difficulty, Leibniz attempted to formulate an *a priori* demonstration of his conservation law. The *a priori* demonstration first appears in the *Dynamica* of 1689-90, and in Leibniz's correspondence starting in 1696 (see *Dynamica,* specimen praeliminare, GM VI 291-92: AG iio-u; *Dynamica* GM VI 345—67; letter to De Voider, 24 March/3 April 1699, GII172-74,· letter to Bayle, 1699-1701, G III 59-60; SD, part I, par. 15, GM VI 243-44: AG 127). Leibniz gives a particularly simple exposition of the argument in a letter to Bayle from the late 1690s:

> In the uniform motion of a single body (1) the action of traversing two places in two hours is double the action of traversing one place in one hour (since the first action contains the second precisely two times); (2) the action of traversing one place in one hour is double the action of traversing one place in two hours (or better, actions which produce the same effect are proportional to their speeds). And thus (3) the action of traversing two places in two hours is four times the action of traversing one place in two hours. This demonstration shows that a moving body receiving a double or triple motion so as to be able to accomplish a double or triple effect in a given time, receives a quadruple or ninefold action. Thus, actions are proportional to the square of speeds. Thus it turns out, most happily, that this accords with my measure of force derived either from experience, or on the grounds of the avoidance of perpetual mechanical motion. (G III 60)

Though it is not at all obvious that "action" as understood in this argument is equivalent to force as understood in the *a posteriori* arguments, as the ability to do work, Leibniz clearly identifies the two,[112] and takes this *a priori* argument to establish the same conclusion as some of the *a posteriori* arguments do, that force is measured by mv^2, and not by Cartesian quantity of motion. Once this is established, the conservation of mv^1 follows directly from the principle of the equality of cause and effect, as above with the *a posteriori* arguments. Despite its surface simplicity, this argument hides a tangle of complexity.[113] But nevertheless, it is obvious why such a strategy should be attractive to Leibniz.

Leibniz's most visible attack on Cartesian physics concerned the conservation principle. But Leibniz also set himself against Descartes' account of impact. Much progress had been made in understanding impact in the years since Descartes first set out his rules, and unlike the conservation principle, only the most blindly dedicated Cartesian could follow the master on the question of impact by the time Leibniz was working out his own mature physics.[114] In this way Leibniz's critique of Descartes' rules of impact did not have the kind of topical interest that the critique of the conservation principle had for his contemporaries.[115] But, nevertheless, Leibniz's critique of the Cartesian laws of impact shows another interesting feature of his own physics.

In his *Principles of Philosophy* of 1644, Descartes set out a general law of impact, followed by seven rules that applied the law to specific cases of direct impact, the situation in which two bodies collide on a straight line. Descartes' law is in two parts. First, if a body *B* collides with another body C that is "stronger" than it is, it will rebound with the same speed it had originally. However, if *B* is stronger than C, *B* will set C into motion, and the two bodies will move in such a way that the total quantity of motion, size times speed, is the same before and after the collision. For bodies in motion, the "strength" of a body is measured by its quantity of motion; when *B* is in motion and C at rest, then the "strength" of C in collision with *B* is the size of C times the speed of *B*.[116]

One of Leibniz's criticisms of this supposed law of impact follows directly out of his critique of the conservation principle. Above we discussed Descartes' claim that the total quantity of motion in the world as a whole is conserved. But Descartes also held that the conservation principle is satisfied in collision,· on Descartes' law of impact, the final speeds of two bodies in impact are determined in such a way that the total quantity of motion in the system is the same before and after the collision. Leibniz found it very easy to use the sorts of arguments he used against the general conservation principle to show that Descartes' law of impact could result in outcomes in which the ability to do work in two bodies is either greatly increased or greatly decreased after impact, (see e.g., letter to Bayle, 9 January 1687, G III 45-46; GM VI123-24).[117] But more interesting is another kind of criticism Leibniz offered.

Important to Leibniz's mature physics is the principle of continuity. In its first public statement in 1687, in a short essay responding to Malebranche's attack on the BD, Leibniz presents the principle as follows:

> When the differences between two instances in a given series or that which is presupposed can be diminished until it becomes smaller than any given quantity whatever, the corresponding difference in what is sought or in their results must of necessity also be diminished or become less than any given quantity whatever. Or to put it more commonly, when two instances or data approach each other continuously, so that one at last passes over into the others, it is necessary for their consequences or results (or the unknown) to do so also. ("Letter of Mr. Leibniz . . .", G III 52: L 351)[118]

Or, to put it more commonly still, "no change happens through a leap" (SD, part II, par. 3, GM VI 248: AG 131). Later we shall see some of the positive consequences this principle has for Leibniz's conception of the physical world, how he uses the principle of continuity to establish that all bodies are elastic to some degree. But it also shows the evident falsity of Descartes' law of impact, Leibniz argues. Consider two bodies, *B* and C, moving with equal speed in opposite directions on the same line. Suppose first that *B* and C are equal (case 1). Then, according to Descartes' laws, both *B* and C will rebound in the opposite direction with the same speed they originally had. But if *B* is even the slightest bit larger than C, then *B* will be "stronger" than C, and *B* will continue in its motion, while C will reverse its motion, keeping its original speed.[119] But, Leibniz notes, "this is an enormous leap from one extreme to another," in violation of his principle of continuity; for however small we make the difference between the sizes of *B* and C, the outcomes will be the same, and will be radically different than if the two bodies were of the same size (see "Letter of Mr. Leibniz . . .", G III 53: L 352). In his 1692 comments on Descartes' *Principles of Philosophy,* Leibniz works the idea out at greater length, and shows the discontinuities in Descartes' rules of impact when we consider two bodies of the same size, and vary the speed and direction of their motion (see GIV 381-84: L 402-3, 412, n. 34).[120]

In this way, Leibniz shows that Descartes' laws of impact cannot be correct. Leibniz's own account of impact is found in the *Dynamica,* as well as in an essay, "Essay de Dynamique sur les Loix du Mouvement. . ." (ED) that probably dates from the early 1690s.[121] Leibniz's account of impact is grounded in a series of conservation laws which, he argues, must be satisfied in impact. Together these laws determine the outcome of a collision between any (elastic) bodies.

First of all, Leibniz holds that the total *absolute force* (living force) in a system of bodies is conserved in an elastic collision,· that is, the sum of mv^2 over all of the bodies is the same both before and after a collision. And so the conservation of living force applies not only to the universe as a whole, but to any closed system of (elastic) bodies within the universe (see GM VI 227-28, 440, 488-89).[122] It should be emphasized that while the conservation of mv^1 in the universe as a whole is absolute and without exception, Leibniz holds, in impact this only holds for perfectly elastic collisions, collisions in which no motion is lost to the smaller parts of bodies. Consider bodies *A* and *B,* with m_A the size of body *A*, and m_E the size of *B*. Then if *A* and *B* are not perfectly elastic, if in collision, motion is lost to their parts, it can happen after the collision that the sum "$m_A v^{\%} + m_B y^2$" is *less than* the sum "$m_A x^2 + m_B z^2$" because of force transmitted to the smaller parts of the two bodies; while such a collision does not result in a loss of total force in the universe, of course, force is not conserved in the motion of the bodies *A* and *B* (see ED, GM VI 230-31).

Next is what Leibniz calls the *conservation of respective speed.* Consider two bodies, *A* and *B,* moving on a straight line, body *A* with velocity *v* before collision and x after, and body *B* with velocity y before collision and z after.[123] (It is important to remember here that we are dealing with velocity, a signed (vector) quantity, and not speed; the sign, positive or negative, indicates the direction of the motion.) Then, Leibniz argues, the following equation holds for elastic bodies in collision:

$$v - y = z - x$$

Leibniz's reasoning here seems to be something like this. In colliding with one another, perfectly elastic bodies do not lose what Leibniz calls their respective force, their ability to act on one another. Furthermore, Leibniz argues, this respective force depends only on their relative velocity; if *A* approaches a resting *B* with velocity *v*, from the point of view of impact it is the same as if *B* approached *A* with that same speed. Now, let *A* and *B* be connected by means of an elastic cord, so that they can act on one another even when moving in opposite directions. In this circumstance, the two bodies can act on one another either coming (through impact) or going (through the cord). Here Leibniz argues that the respective force will be the same when the relative speeds, either *A* and *B* approaching one another or receding, are the same. And so, Leibniz argues, when A and *B* collide elastically, their relative velocities must be the same before and after the collision, otherwise their respective force would differ before and after the collision.[124] It is important to note that as with the conservation of absolute force, the conservation of respective speed is limited to perfectly elastic collisions; when motion can be lost to the smaller parts to make up *A* or *B*, then respective force can be lost and this equation will not necessarily be satisfied.

In addition to these, Leibniz presents a third law, what he calls the *conservation of common progress.* In accordance with this law, the following equation holds for all bodies in collision:

$$m_A v + m_B y = m_A x + m_B z$$

This law, of course, is what has come to be called the conservation of momentum, though Leibniz never used the term. The quantity, size times velocity that appears in this law must be carefully distinguished from the Cartesian notion of quantity of motion. According to Descartes and his followers, what is conserved in impact (and in the world as a whole) is size times *speed,* a scalar quantity that does not involve direction. While Descartes is concerned about what happens to directionality of motion in impact, considerations of directionality don't enter into his conservation principle in any way; a body hitting another and rebounding with the same speed has the exact same quantity of motion before and after the collision.[125] In Leibniz's physics what is conserved is not size times speed, but size times *velocity,* a vector quantity, speed together with direction; this he calls progressive or directional force, to distinguish it from the Cartesian notion of quantity of motion. And so, when a body reverses its motion after collision, its progressive or directional force is changed. Leibniz derives the conservation of common progress in the following way. He first argues that in a (closed) system of bodies, no collision among the bodies should change the speed or direction of the center of gravity of the aggregate, a conclusion that he takes to follow from the conservation of living force in the universe. And from this it follows, Leibniz argues, that in the aggregate, the totality of progressive or directional force must remain the same, whatever collisions there might be among the bodies in the aggregate. This law, it should be observed, holds for both elastic and nonelastic collisions,· even if motion is lost to the smaller parts of larger bodies, the center of gravity of the aggregate should continue at the same speed in the same direction.[126]

These three laws are interconnected, Leibniz argues, and show how from any two the third can be derived (see ED, GM VI 228). Moreover, any two of them are sufficient for solving the problem of collision between two elastic bodies. Nevertheless, it is the conservation of absolute force, mv^2 in impact that Leibniz considers the most significant. In the beginning of the ED, Leibniz complains that many who have come to recognize the failure of the Cartesian conservation principle "have thrown themselves to the other extreme, and recognize no conservation of anything absolute that can take the place of the quantity of motion" (ED, GM VI 216). But, Leibniz says, in the conservation of mv^2 we have the conservation of an absolute, that is, a quantity that does not involve direction, unlike the conservation of respective speed or the conservation of common progress, which inevitably involve signed quantities. Leibniz writes in the ED, immediately following the exposition of the conservation of absolute force:

> This equation has an excellent feature, that all of the variations in sign which can only come from the different direction of the speeds v, x, z, y, cease, because all of the letters which express these speeds are here raised to the square. For $-y$ and $+y$ have the same square, , so that all of the different directions mean nothing here. And it is also for this that this equation gives something absolute, independent of respective speeds or of

the progress in a certain direction. We have only to estimate the different masses and speeds, without taking account of the direction of these speeds.
(GM VI 227-28)

While Leibniz is not explicit here, I suspect that his preference for an absolute conservation principle is connected with his own views on relations. For Leibniz, as we noted above in section 4.2, in connection with motion, something that is merely relative is not really real insofar as it cannot really have a subject. Absolute force, mv^1, though, is something that can be attributed to some one body; it is a present property of a body by virtue of which it has the ability to do work in the future.

Leibniz's arguments for the laws of motion all depend in one way or another on certain metaphysical principles, particularly the principle of the equality of cause and effect and the principle of continuity. Because of this, Leibniz argues, the laws of motion are contingent, and display the wisdom of God in choosing this best of all possible worlds.[127] Leibniz writes, for example, in the *Theodicy:*

I have discovered ... that the laws of motion which are actually found in nature, and are verified by experience, are not in truth absolutely demonstrable, as a geometrical proposition would be. They do not derive entirely from the principle of necessity, but from the principle of perfection and order; they are an effect of the choice and the wisdom of God. I can demonstrate these laws in many ways, but it is always necessary to assume something which is not absolutely geometrically necessary.
[Theodicy, part I, par. 345 G VI 3r9; cf. *Discourse,* par. 2r, G IV 446-47: AG 53-54)

But if the laws of motion are contingent in this way, how can Leibniz establish them by argument?

In his writings on physics, Leibniz simply assumes the metaphysical principles he needs and does the derivations from them, in essence simply assuming that the world we live in is a world created by a benevolent and wise God, who imposes such principles of order on his creation. This assumption is further supported by the fact that the laws so derived seem to be able to explain what actually happens in the world of bodies. And so, for example, when discussing with de Voider why the principle of the equality of cause and effect must be satisfied in our world, he remarks that a world "in which matter at rest obeys that which puts it in motion without any resistance" is both possible and imaginable, but, he notes, "such a world would be mere chaos." Leibniz continues:

And so, two things on which I always rely here, success in experience and the principle of order, brought it about that I later came to see that God created matter in such a way that it contains a certain repugnance to motion.

(Letter to De Voider, 24 March/3 April 1699, G II 170-71:AG 172)

Experience and our belief that the world is not a chaos then lead us away from the geometrical conception of the laws of motion Leibniz represents himself as having held in the TMA and the HPN, and toward the contingent laws he presents in his later writings; in this way we can have a kind of demonstration of the contingent truths which govern our mechanical world.

Leibniz sometimes argues in the other direction, using the empirical adequacy of the laws derived from metaphysical principles to argue for the existence of a wise and benevolent creator who laid down the metaphysical principles that govern motion. In the passage from the *Theodicy* quoted above Leibniz ends as follows:

These beautiful laws are a marvelous proof of an intelligent and free being [i.e., God], against the system of absolute and brute necessity of Straton and Spinoza.

[*Theodicy,* pt. I, par. 345, G VI 319; cf. *Principles of Nature and Grace,* par. 11, G VI 603: AG 211]

The dependence of the laws of motion on God's choice of the best of all possible worlds and the consequent contingency of the laws of motion are very important to Leibniz. For one, it provides a nice argument against those, like Spinoza, who see everything as necessary. Leibniz writes to Remond:

You are right, Sir, to judge that [my dynamics] is in good part the foundations of my system, because one learns there the difference between the truths whose necessity is brute and geometrical, and those truths which have their source in fitness and final causes.

(Letter to Remond, 22 June 1715, G III 645)

But also important to Leibniz was the fact that the contingency of the laws of motion brings God into the mechanical philosophy. He writes, for example, in the *"Tentamen Anagogicum"* of 1696:

This consideration gives us the middle term needed to satisfy both truth and piety... : all natural phenomena could be explained mechanically if we understood them well enough, but the principles of mechanics themselves cannot be explained geometrically, since they depend on more sublime principles which show the wisdom of the Author in the order and perfection of his work. (G VII 272:L 478)

In this way, the laws of motion lead us to see more generally the importance of considering final causes in physics, as we shall later discuss.[128]

4.4 Atomism and elasticity

The new mechanical philosophy of the seventeenth century was closely connected with the revival of interest in ancient atomism in the late sixteenth and early seventeenth centuries. While there are a number of important figures connected with the revival of atomism, Pierre Gassendi is the most prominent. An editor, translator into Latin, and commentator on the Epicurean tracts preserved by Diogenes Laertius, Gassendi represented one of the main streams of early modern mechanist thought.[129] At the time Gassendi was producing his tomes in defense of an up-dated atomism, Descartes was working out a different conception of the mechanical philosophy. For the atomists, the world was made up of a void filled with atoms, small parts of matter that are perfectly hard, unsplittable, indestructible, at least by natural means. Descartes denied both. For him, the world was made up of matter infinitely divisible, and in some cases actually divided to infinity, that filled up all space.[130] Some, like Boyle, tried to set aside the debate and reject the question as to the infinite divisibility of matter or the existence of a real space, entirely empty of body.[131] But for most writing after Gassendi and Descartes, one had to make a choice.

Though Leibniz may intially have sided with Gassendi and the atomists, in his mature writings he clearly rejected atomism. We saw his rejection of the void in section 4.x. But Leibniz also had a variety of arguments directed against the existence of atoms. In some places he argues against the existence of atoms from his principle that no two things in the world can be perfectly similar. While the argument is not altogether clear, his idea seems to be that if there were only one kind of matter, and it was always perfectly hard,

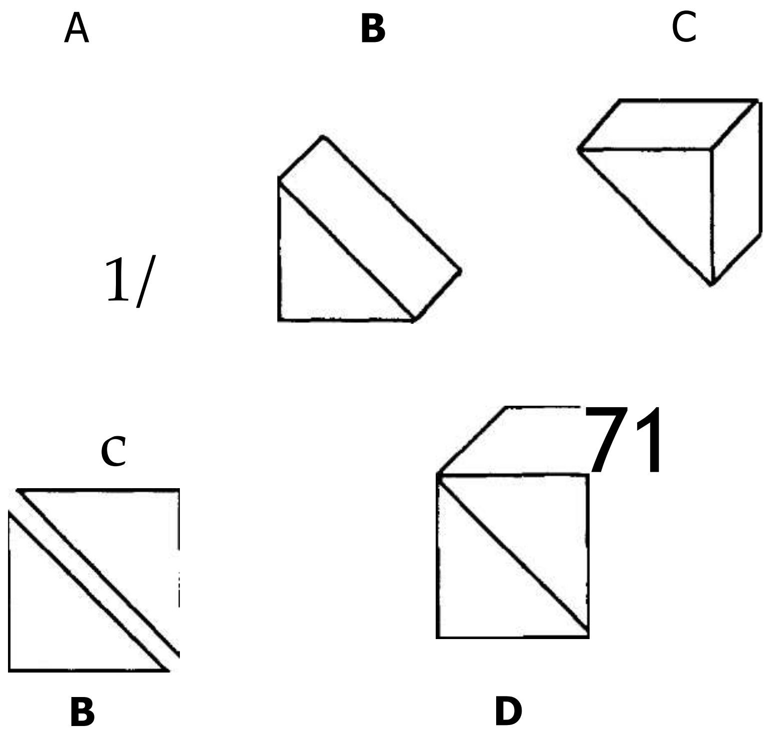

Figure 2

then there could be no physical features to distinguish pieces of it of the same volume (see e.g., "On Nature Itself," par. 13, GIV 514: AG 164; letter to De Voider, 20 June 1703, GII250: AG 175; *New Essays,* Preface, A Vl.vi: RB 57). In notes from October 1690, Leibniz formulated a different kind of argument, a kind of *reductio ad absuidum* of the idea of an atom. Assuming that atoms can come in all shapes, Leibniz hypothesizes a cubical atom, *A,* and two atoms in the shape of triangular prisms, *B* and C, that together make up a cube *D* of the same volume as *A* (see figure 2). When *B* and *C* come together to form *D,* then *D* is indistinguishable from *A,* Leibniz argues. And so, he claims, either *A* is made up of smaller parts, and is thus not an atom, or *D* is an atom, and is not made up of smaller parts, as hypothesized.[132] In the correspondence with Clarke, Leibniz suggests that it is the Principle of Sufficient Reason that undermines the hypothesis of atomism, since there can be no reason for stopping the divisibility (or, for that matter, the actual division) of matter at one place rather than another (see fourth letter to Clarke, Postscript, G VII 377-78: AG 332).

But there is one argument that Leibniz uses over and over, and returns to often, an argument from the principle of continuity. According to the principle of continuity, no change in nature happens through a leap. Now, Leibniz argues in part II of the SD:

> If we were to imagine that there are atoms, that is, bodies of maximal hardness and therefore inflexible, it would follow that there would be a change through a leap, that is, an instantaneous change. For at the very moment of collision the direction of the motion reverses itself.
> (SD, part II, par. 3, GM VI 248: AG r32; cf. G IV 398-99: AG 255; ED, GM VI 229; *Dynamica,* GM VI 491)

If bodies were perfectly hard, and had no "give" in them, then when they collided with one another, they would instantaneously change their direction and speed. And so, Leibniz argues, there can be no atoms, no perfectly hard and inflexible bodies in nature, on pain of violation of the principle of continuity.

This argument refutes the supposed existence of atoms, Leibniz thinks. But it also does a great deal more. From the general form of the argument one can establish not only that there are no atoms, but also that there are no bodies whatsoever that are inflexible. That is, as Leibniz writes again in the SD, "no body is so small that it is without elasticity" (SD, pt. II, par. 3, GM VI 249: AG 132; cf. *Dynamica,* GM VI 491).[133] But, Leibniz argues, if all bodies are elastic, then all bodies must be made up of smaller parts. Elasticity, for Leibniz as for his mechanist contemporaries, was not a basic property of matter, but one that was to be explained mechanically in terms of the configuration of parts that make up a given body. Leibniz writes in the ED, for example, that

> Elasticity ought always to derive from a more subtle and penetrating fluid, whose movement is disturbed by the tension or by the change of the elastic body.
> (ED, GM VI 228; cf. "On Nature Itself," par. r4, G IV 5x5: AG 165; letter to Burnett, 1699, G III 260: AG 289).[134]

Leibniz continues:

> And since this fluid itself ought to be composed, in turn, of small solid bodies, themselves elastic, one well sees that this replication of solids and fluids goes to infinity.
> (ED, GM VI 228) cf. SD, part II, par. 3, GM VI 248-49: AG 132-33)

From the principle of continuity, we reach the conclusion that the actual division of matter into smaller parts proceeds to infinity.

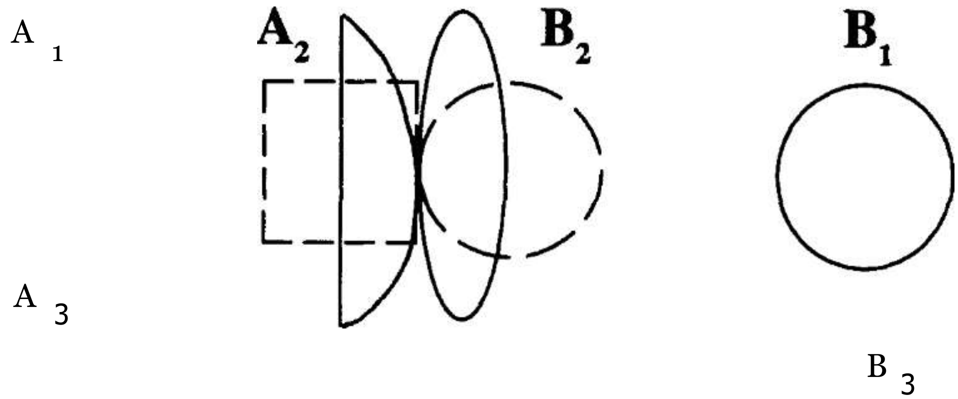

Figure 3

Leibniz draws another interesting consequence from the fact that everybody is elastic to some degree. Leibniz considers the case of two elastic bodies in collision. What happens, he says, is that in collision both bodies first become compressed and deformed; it is by virtue of their elasticity that they return to their original shapes, and in so doing, push themselves off from one another, so to speak (see fig. 3). And so, Leibniz concludes:

> The repercussion and bursting apart [of a body in impact] arises from the elasticity it contains, that is, from the motion of the fluid aetherial matter permeating it, and thus it arises from an internal force or a force existing within itself.
> (SD, part II, par. 5, GM VI 251: AG 135,· cf. "New System," G IV 486: AG 145; "On Nature Itself," par. 14, G IV 515: AG 165; G IV 397, 399: AG 254, 2.55-56)

In this way, he writes,

> Bodies . . . always gain their motion in collision from their very own force, to which the impulse of another body provides only the occasion for acting and a limitation, so to speak. (G IV 397: AG 254)

In this way, Leibniz claims in the "First Truths" paper of 1689, we have in nature an illustration of the metaphysical doctrine in accordance with which "no created substance exerts a metaphysical action or influx on any other thing" (C 521: AG 33).[135]

The doctrine of the elasticity of all body plays a central role in Leibniz's mature thought about the physical world. But it does have one odd and noteworthy feature. At the end of section 1,1 discussed an important difference between Leibniz's early physics and the mature thought that emerged in the late 1670s. In the mature thought, metaphysical principles, like the principle of the equality of cause and effect, are woven into the basic fabric of the physical world, and made basic constraints on the activity of the corporeal substances that constitute the basis of Leibniz's physics. This is unlike the earlier treatment of such principles, which, if satisfied at all, were an *ad hoc* result of the state of the world; it is only because of the particular make-up of bodies in the HPN that a smaller body will lose motion when setting a larger resting body into motion, for example. But, I think, the doctrine of elasticity provides an interesting exception to this general tendency in Leibniz's later thought. For the doctrine that every body in the world must be elastic derives from the metaphysical (and contingent) principle of continuity; it is because the principle of continuity must be satisfied that bodies must be made up of smaller parts in such a way that they tend to restore themselves to their original state, when deformed. But that is to say that the metaphysical principle of continuity is satisfied in this world *only* because of the particular physical state of bodies in this world. In the doctrine of elasticity we see, as it were, a ghost of Leibniz's earlier thought.

5. GOD, MIND, AND THE MECHANICAL PHILOSOPHY

In the previous sections, I have outlined Leibniz's physics and its grounding in his program for dynamics. In this final section, I would like to address some larger questions about the place of Leibniz's physics in his system.

5.1 *God, final causes, and the world of physics*

The discussions earlier in this essay have shown the extent to which Leibniz's physics, his mechanical philosophy, and his dynamics are intimately intertwined with his conception of God, benevolent ruler of the world, who has chosen to create this best of all possible worlds, governed by the metaphysical principles that determine the laws of motion that bodies in the world obey. As Leibniz often puts it, everything within the world is explicable mechanistically but the laws themselves, which require appeal outside the world of the mechanical philosophy to a divine creator. In this way, Leibniz quite self-consciously reintroduces into physics the final cause that had been banished by earlier mechanists.

The final cause was, of course, a central notion in Aristotelian natural philosophy; indeed, for many, including perhaps Aristotle himself, it was the most important of the four causes.[136] But when the philosophy of the schools came under attack, so did final causes. Descartes, for example, argued in his *Principles of Philosophy:*

> When dealing with natural things we will, then, never derive any explanations from the purposes which God or nature may have had in view when creating them and we shall entirely banish from our philosophy the search for final causes. For we should not be so arrogant as to suppose that we can share in God's plans.[137]

For Descartes, then, our ignorance of God's intentions prevents us from appealing to final causes in physics. Spinoza goes Descartes one better and denies that God has any intentions at all. He writes in his *Ethics:*

> [There is] a widespread belief among men that all things in Nature are like themselves in acting with an end in view. Indeed, they hold it as certain that God himself directs everything to a fixed end; for they say that God has made everything for man's sake and has made man so that he should worship God. . . . There is no need to spend time in going on to show that Nature has no fixed goal and that all final causes are but figments of the human imagination. For I think that this is now quite evident [from discussions earlier in the *Ethics]*. . . that all things in Nature proceed from an eternal necessity and with supreme perfection.[138]

Not all mechanical philosophers followed Descartes and Spinoza in rejecting final causes, of course.[139] But final causes were clearly under attack, and Leibniz saw his role as defending them.

Leibniz's defense of final causes is, in a way, at the center of his metaphysics, and stands behind his whole account of contingency and divine freedom. But it also has a dimension that relates more specifically to his physics. We have already seen the way in which God's action reaches to the determination of the laws of motion; God creates substances in the world in such a way that they satisfy certain metaphysical principles like the principle of the equality of cause and effect and the principle of continuity, and because of that, they satisfy the sorts of conservation principles that Leibniz posits as basic in the world of bodies. But Leibniz sees final causes as more generally relevant for physics as well. Leibniz writes in the SD:

In general, we must hold that everything in the world can be explained in two ways: through the *kingdom of power,* that is, through *efficient causes,* and through the *kingdom of wisdom,* that is, through *final causes,* through God, governing bodies for his glory, like an architect, governing them as machines that follow the *laws of size* or *mathematics,* governing them, indeed, for the use of souls. . . . These two kingdoms everywhere interpenetrate each other without confusing or disturbing their laws, so that the greatest obtains in the kingdom of power at the same time as the best in the kingdom of wisdom. (SD, part I, par. 14, GM VI 243: AG 126-27)

A special domain, as it were, within the kingdom of wisdom is what Leibniz calls the kingdom of grace. He writes in the *Monadology:*

Since earlier we established a perfect harmony between two natural kingdoms, the one of efficient causes, the other of final causes, we ought to note here yet another harmony between the physical kingdom of nature and the moral kingdom of grace, that is, between God considered as the architect of the mechanism of the universe, and God considered as the monarch of the divine city of minds. . . . This harmony leads things to grace through the very paths of nature. For example, this globe must be destroyed and restored by natural means at such times as the governing of minds requires it, for the punishment of some and the reward of others.
[*Monadology,* pars. 87-88, G VI 622: AG 224)

The world of the mechanical philosophy is in harmony with the kingdoms of wisdom and grace, Leibniz claims. Everything in the physical world that can be explained through God can be explained mechanically (assuming the laws of motion), and everything that can be explained mechanically can be explained through God as well. This amounts to saying that everything that the mechanical philosophy explains is a direct consequence of God's choice and design, not *just* the laws of mechanism, but *every particular* as well.[140] Leibniz writes in the *Discourse on Metaphysics:*

Anyone who sees the admirable structure of animals will find himself forced to recognize the wisdom of the author of things. And I advise those who have any feelings of piety and even feelings of true philosophy to keep away from the phrases of certain so-called free-thinkers, who say that we see because it happens that we have eyes and not that eyes were made for seeing. (*Discourse,* par. 19, G IV 445: AG 52-53)

As a result, Leibniz suggests that we can appeal to God's wisdom in dealing with specific problems in physics, where proceeding by way of efficient causes is too complicated, particularly in optics (see SD, part I, par. 14, GM 243: AG 126; G III 51-52: L 351; *Discourse,* par. 22, G IV 447-48: AG 54-55).[141] Furthermore, the harmony between the two kingdoms means that when God realizes his intentions in the world he created, he realizes them through mechanical means; God has reasons for everything in his creation, but this does not undermine the scope of Leibniz's mechanism. As Leibniz suggests in the passage quoted above, even Noah's flood can be explained mechanically.

But even though everything *can* be explained in terms of God, Leibniz doesn't think that everything *should* be so explained. In the May 1702 essay, Leibniz writes:

It is empty to resort to the first substance, God, in explaining the phenomena of his creatures, unless his means or ends are, at the same time, explained in detail, and the proximate efficient or even the pertinent final causes are correctly assigned, so that he shows himself through his power and wisdom. (G IV 397-98AG 254)

Everything can, of course, be explained in terms of God, Leibniz holds. But unless specific details are given, the explanation is without content; to say that there was a universal deluge because God willed it to be so is an explanation that can be used to explain *anything* at all in the world. What we need to turn such an explanation into something with content is the specific reason that God had for flooding the world when he did, and the means by which he accomplished that end.

5.2 *Soul, form, and gravity*

In the *Theodicy,* Leibniz rehearsed an argument that he especially liked:

M. Descartes wanted ... to make a part of the action of the body depend on the mind. He thought he knew a rule of nature which, according to him, holds that the same quantity of motion is conserved in bodies. He did not

judge it possible that the influence of the mind could violate this law of bodies, but he believed, however, that the mind could have the power to change the direction of the motions which are in bodies . . . [but] two important truths on this subject have been discovered since M. Descartes. The first is that the quantity of absolute force which, indeed, is conserved, is different from the quantity of motion, as I have demonstrated elsewhere. The second discovery is that the saine direction is conserved among all of those bodies taken together which one supposes to act on one another, however they may collide. If this rule had been known to M. Descartes, he would have rendered the direction of bodies as independent of the mind as their force. And I believe that this would have led him directly to the hypothesis of pre-established harmony, where these rules led me. Since beside the fact that the physical influence of one of these substances on the other is inexplicable, I considered that the mind cannot act physically on the body without completely disordering the laws of nature.
(*Theodicy,* pars. 60-6r, G VI 135-36; cf. *Monadology,* par. 80, G VI 620-2r: AG 223; letter to Arnauld, 30 April 1687, G II 94: AG 83-84; letter to Remond, ro January *1714.,* G III 607: L 655; G IV 497-98; G VI 540: L 587.)

Seventeenth century philosophers grappled with the problem of understanding how it is that rational, sentient, creatures like us can fit into the world of the mechanical philosophy. This problem was especially difficult for those like Descartes and his followers who posited an immaterial, incorporeal mind or soul, attached to the human body, the source of its voluntary motions.[142] For Descartes, of course, the mind can directly cause changes in the body, and for his occasionalist followers, a volition in the mind can cause a bodily change with the intermediation of God. But this raises a problem for the mechanical philosophy. For if mind can be the cause of bodily change, either a direct cause or an occasional one, then the mind can cause violations in the laws of nature, it would seem. Leibniz attributes to Descartes the view that the mind can change the direction in which some part of the body is moving, but not its speed, thus allowing his conservation principle, the conservation of quantity of motion, to be satisfied even in the case of voluntary motion.[143] But, Leibniz remarks, with the Cartesian law overthrown, this is not possible. Among the laws that Leibniz proposes is what we called the conservation of common progress discussed in section 4.3, what we now call the conservation of momentum. This conservation law, which holds in both elastic and nonelastic collisions, would be violated were mind able to change the direction in which a body were moving. What we need, Leibniz thinks, is some way of preserving the laws of nature from violation while allowing for living creatures whose behavior is determined, at least in part, by something apparently outside of the material world. Leibniz's solution is pre-established harmony.

The doctrine of pre-established harmony is best known as a solution to the problem of mind-body interaction and to the problem of how it is that a mind could cause a change in a body (see, e.g., G IV 498-500: AG 147-49). But it is more than that; it is a solution to the problem of how to understand living creatures existing in a mechanical world. In presenting his views Leibniz, again, uses the image of two kingdoms, though somewhat differently than he uses it in connection with God above. Leibniz writes in the *Monadology:*

> The soul follows its own laws and the body also follows its own; and they agree in virtue of the harmony pre-established between all substances, since they are all representations of a single universe.. . . Souls act according to the laws of final causes, through appetitions, ends, and means. Bodies act according to the laws of efficient causes or of motions. And these two kingdoms, that of efficient causes and that of final causes, are in harmony with each other.... According to this system, bodies act as if there were no souls (though this is impossible); and souls act as if there were no bodies; and both act as if each influenced the other.
>
> [*Monadology,* pars. 78, 79, 81: G VI 620-21: AG 223; cf. "Antibarbarus physicus," G VII 344: AG 319; fifth letter to Clarke, par. 124, G VII 419: AG 345-56)

And so, Leibniz holds, what goes on in living creatures can be explained either mechanically, in terms of size, shape, and the laws of motion, or in accordance with the activity of the soul; the two, Leibniz claims, will always correspond. And so we have mind-body interaction of a sort, without any violation of the laws of nature.

It is important to remember here that this account holds quite generally for Leibniz, for, as we discussed above in sections 3.2 and 3.3, Leibniz holds that there are living things everywhere in his world. All body is grounded in corporeal substances that are composed of a unity of primitive active and primitive passive force. Or, since Leibniz identified the primitive active force with form or soul, and the primitive passive force with matter or body, these corporeal substances that ground the physical world can be thought of as Aristotelian substances, unities of form and matter that constitute living creatures, as we discussed above. And so, he argues, the world is filled with living creatures like us in having souls and bodies. Leibniz writes to Thomas Burnett in 1697:

> I believe that everything happens mechanically, as Democritus and Descartes hold . . . and that nevertheless everything also happens vitally and in accordance with final causes, everything being full of life and perceptions, contrary to the opinion of the Democriteans.
>
> (Letter to Burnett, 24 August 1697; G III *217)*

Similarly, Leibniz wrote to Des Billettes in 1696:

> I believe that everything really happens mechanically in nature, and can be explained by efficient causes, but that, at the same time, everything also takes place morally, so to speak, and can be explained by final causes. These two kingdoms, the moral one of minds and souls and the mechanical one of bodies, penetrate each other and are in perfect accord through the agency of the Author of things, who is at the same time the first efficient cause and the last end.
>
> (Letter to Des Billettes, 4/14 December *1696,* G VII 45r: L 472; cf. letter to Conring, 19 March r678, G I r99: L r90; G IV 559-60: L 577-78)

Not only can the voluntary activity of human beings be explained in terms of soul; *everything* in the world can be so explained, because at root, there are living creatures, souls attached to bodies *everywhere* in nature. Or, to put it equivalently, since these living creatures are corporeal substances, unities of matter and form, everything can be explained as the schoolmen do. But at the very same time, *everything* in nature can also be explained mechanically, even the voluntary motions of creatures like us.[144] In this way Leibniz quite self-consciously reconciles the philosophy of the schools with the most radically mechanistic philosophy of the moderns,· both are correct, and the two pictures will always agree with one another. Leibniz writes in the *Discourse* that "the thoughts of the theologians and philosophers who are called scholastics are not entirely to be disdained. . . . [T]hey are not so distant from the truth or so ridiculous as the common lot of our new philosophers imagines" *[Discourse,* par. 11, G II12: AG 43,· par. 10, G IV 434: AG 42).

When dealing with human minds and bodies, we can and should explain particular voluntary actions in terms of the volition of the mind whenever we can. However, this is not so more generally when dealing with the animate corporeal substances that make up Leibniz's physical world. Though everything *can* be explained in terms of the forms Leibniz recognizes in nature, they should not be used to explain particulars; their proper function, Leibniz holds, is just to ground the general laws in terms of which particular phenomena *should* be explained. Leibniz explains in the *Discourse on Metaphysics:*

I agree that the consideration of these forms serves no purpose in the details of physics and must not be used to explain particular phenomena. That is where the Scholastics failed, as did the physicians of the past who followed their example, believing that they could account for the properties of bodies by talking about forms and qualities, without taking the trouble to examine their manner of operation. It is as if we were content to say that a clock has a quality of clockness derived from its form without considering in what all of this consists; that would be sufficient for the person who buys the clock, provided that he turns over its care to another.

(Discourse, par. 10, G IV 434: AG 42; cf. letter to Arnauld, 14 July 1686, G II 58; G IV 345-46; G IV 397-98: AG 254-5; "New System," G IV 479: AG 139; "Specimen Inventorum," G VII 317; SD, part I, par. 13; GM VI 242-43: AG 125-26]

Leibniz holds that the world of physics must be grounded in an Aristotelian world of corporeal substances, form and matter, tiny organisms, and that everything can be explained in those terms. But, he holds, while such explanations are always true, they are rarely informative, indeed, even more rarely than the appeal to God, and so while Leibniz holds that the Schoolmen are not to be despised, they are not to be followed either.

This is close to his attitude toward certain other dissidents from the new mechanical philosophy. Henry More, the Cambridge Platonist, among others, saw the mechanical philosophy as valuable, not primarily for the explanations that it gave, but for the explanations that it couldn't give,· for More and his cohorts, by showing clearly what could be explained in physics, the mechanical philosophy showed clearly what couldn't and provided the best argument for the necessity of something outside of the mechanical world. Consequently, they posited a variety of immaterial substances to explain everything from ghosts and hauntings to gravity.[14]' Leibniz objected in the SD:

However, even though I admit an active and, so to speak, vital principle superior to material notions everywhere in bodies, I do not agree with *Henry*

More and other gentlemen distinguished in piety and ability, who use an Archaeus (unintelligible to me) or hylarchic principle even for dealing with the phenomena, as if not everything in nature can be explained mechanically. . . . With these views, I say, I do not agree, and such a philosophy pleases me no more than that theology of certain men, who believed that Jupiter thundered and caused the snow to such an extent that they even defamed those who investigated more particular causes with the charge of atheism. In my opinion the middle way in which one satisfies both piety and knowledge is the best. That is, we acknowledge that all corporeal phenomena can be derived from efficient and mechanical causes, but we understand that these very mechanical laws as a whole are derived from higher reasons.

(SD, part I, par. 13, GM VI 242: AG 125-26; cf. "On Nature Itself," par. 2, G IV 505: AG 156; "Antibarbarus physicus," G VII 339-40: AG 314-15)

And so, while Leibniz agrees with More in rejecting the narrow mechanist ontology of extended substances, and adding active principles to nature, he doesn't think that they should be used for explaining particular phenomena, any more than the forms of the schoolmen should.[146]

It is in this context that we must understand Leibniz's reaction to Newton's theory of universal gravitation. In his *Principia,* Newton argued that all bodies in the universe attract one another by way of a force that varies inversely with the square of the distance. Leibniz certainly accepted this, at least with regard to what it is that keeps the planets in their orbits.[147] But in other regards he was decidedly hostile. While Newton's own attitude was not altogether clear on this, one could get the impression from Newton, and, indeed, one did get the clear view from some of his followers, that the universal gravitation of the *Principia* was intended to be a basic, irreducible, and inexplicable property of matter as such, something that one need not and could not explain mechanically.[148] It was this that Leibniz objected to and saw as a revival of the worst abuses of the scholastics. In an unpublished essay, the "Antibarbarus Physicus," Leibniz wrote:

It is, unfortunately, our destiny that, because of a certain aversion toward light, people love to be returned to darkness. We see this today, where the great ease for acquiring learning has brought forth contempt for the doctrines taught, and an abundance of truths of the highest clarity has led to a love for difficult nonsense. . . . It is permissible to recognize magnetic, elastic, and other sorts of forces, but only insofar as we understand that they are not primitive or incapable of being explained, but arise from motions and shapes. However, the new patrons of such things don't want this. And it has been observed that in our own times there was a real suggestion of this view among certain of our predecessors who established that the planets gravitate and tend toward one another. It pleased them to make the immediate inference that all matter essentially has a God-given and inherent attractive power and, as it were, mutual love.. . . [They argue] as if there were no room for mechanical explanations by which [the attraction] ... could be accounted for through the motion of smaller pervading bodies. These same people threaten to give us other occult qualities of this sort, and thus, in the end, they may lead us back to the kingdom of darkness.

(G VII 337-38: AG 312, 313-14)

The particular kingdom of darkness Leibniz has in mind here is, of course, the natural philosophy of the Scholastics. For, if we allow the Newtonians their force of attraction, Leibniz argues in the preface to the *New Essays,* "I do not see what would prevent our Scholastics from saying that everything happens through faculties" (A Vl.vi: RB 61). By implication, the Newtonian explanation of gravitation is as empty as the explanation of the properties of a time piece in terms of its innate clockness.

Leibniz sometimes adds another consideration, and argues that for God to impose such behavior on bodies as the Newtonians imagine he does would be miraculous. He writes in the correspondence with Clarke:

If God wanted to cause a body to move free in the aether round about a certain fixed center, without any other creature acting upon it, I say it could not be done without a miracle, since it cannot be explained by the nature of bodies. For a free body naturally recedes from a curve in the tangent. And therefore, I maintain that the attraction of bodies, properly so called, is a miraculous thing, since it cannot be explained by the nature of bodies.

(Third letter to Clarke, par. 17, G VII 366-67: AG 327,· cf. fourth letter to Clarke, par. 45, G VII 377: AG 232; fifth letter to Clarke, pars. 35, 112-13, 118, G VII 417, 418: AG 336, 344, 345)

It would be a miracle for God simply to move bodies as the Newtonians claim he does. But, Leibniz thinks, it would be no miracle for him to structure the world in such a way that through mechanical causes, things in the world behaved as Newton described them. Interesting as this argument is, though, I am not sure that Leibniz is really entitled to it. For the Newtonians are not claiming that God simply moves bodies, but that God has given bodies such a nature that they attract one another in the appropriate way, and that such a nature directly gives rise to the Newtonian law of universal gravitation, without there being any mechanical cause. Their claim is not that the attraction of bodies for one another goes beyond their nature, but that their nature is something different than Leibniz (and other stricter mechanists) think it is.

Couldn't God have given bodies such a nature? Perhaps, but if so, then the mechanist's standard of intelligibility, explicability of everything in the world in terms of bodies colliding with one another in accordance with the laws of motion, must be wrong. And if it is wrong, then the world is forever unintelligible to us, Leibniz thought. Leibniz wrote to Herman Conring on 9 March 1678, at the very point at which his mature physics is beginning to emerge:

> I recognize nothing in the world but bodies and minds . . . and [nothing] in bodies insofar as they are separated from mind but magnitude, figure, situation, and changes in these. Everything else is merely said, not understood; it is sounds without meaning. Nor can anything in the world be understood clearly unless it is reduced to these. . . . Unless physical things can be explained by mechanical laws, God cannot, even if he chooses, reveal and explain nature to us. (G I 197: L 189)

Leibniz seems to have retained this attitude throughout his life. While he did his best to make peace with the schoolmen and reconcile his mechanism with their views, he was utterly unprepared for the reintroduction of specific innate tendencies into the world in the form of a Newtonian attractive force. By the time he died in 1716, the strict mechanism that had been so modern and so daring in his youth, the view around which he built his metaphysical physics, was well on its way to becoming an anachronism.[149]

NOTES

1 Unfortunately, space will not permit discussion of another important feature of Leibniz's physics, his use of the newly developed calculus in his work from the mid-1680s on. For a discussion of this, see Blay, *La naissance de la mécanique analytique,* pp. r 13-52.

2 For representative developments of the foundations of Aristotelian natural philosophy, see, e.g., St. Thomas Aquinas' *De piincipiis naturae,*

translated in *Selected Writings of St. Thomas Aquinas,* ed. and trans., Goodwin,· part III of Eustachius a Sancto Paulo's *Summa Philosophiae Quadripartita,* a popular textbook originally published in 1609, but often reprinted later; and Scipion Dupleix, *La physique,* originally published in 1603, also reprinted later, and now available in an edition edited by Roger Ariew, based on the 1640 edition. For modern accounts, see, e.g., Grant, *Physical Science in the Middle Ages* and Lindberg, ed., *Science in the Middle Ages.*

3 On the transmission of Aristotelian texts in the twelfth and thirteenth centuries, see, e.g., Dod, "Aristoteles Latinus," in Kretzmann, Kenny, and Pinborg, eds., *The Cambridge History of Later Medieval Philosophy,* pp. 45-79/ and Lohr, "The Medieval Interpretation of Aristotle," in Kretzmann, Kenny, and Pinborg, *op. cit.,* pp. 82-98. For the thirteenth century condemnations, see Dod and Lohr *passim,* as well as Grant, "The Condemnation of 1277, God's Absolute Power, and Physical Thought in the Late Middle Ages," pp. 211-44. Attacks in the thirteenth century mostly came from conservative theologians whose more traditional ideas were in danger of being displaced by the new Aristotelian fashions. By the fifteenth and sixteenth centuries, Aristotelianism is the established philosophy, and the attacks come now from the innovators, from Humanists, sceptics, advocates of some variety of Platonism, Hermeticism, etc. See, e.g., Ingegno, "The New Philosophy of Nature," in Schmitt and Skinner, *The Cambridge History of Renaissance Philosophy,* pp. 236-63, and Menn, "The Intellectual Setting of Seventeenth-Century Philosophy," in *The Cambridge History of Seventeenth-Century Philosophy.* Despite later attacks, Aristotelian philosophy, including the Aristotelian natural philosophy, was central to the colleges and universities well into the seventeenth century. See Schmitt, *Aristotle and the Renaissance.*

4 For a survey of the mechanical philosophy, see Dijksterhuis, *The Mechanization of the World Picture,* and Westfall, *The Construction of Modern Science: Mechanisms and Mechanics.* For seventeenth century attempts to reconcile Aristotle and the new mechanical philosophy, with special reference to Leibniz, see especially Mercer, "The Seventeenth-Century Debate Between the Moderns and the Aristotelians: Leibniz and the Philosophia Reformata," in Marchlewitz and Heinekamp, eds., *Leibniz' Auseinandersetzung mit Vorgängern und Zeitgenossen,* and her *Leibniz's Metaphysics: Its Origins and Development.*

5 For Leibniz's earliest education, see Chap. 2 in this *Companion.*

6 Leibniz's own account of his turn toward the Moderns is found in his letter to Nicolas Remond, 10 January 1714, G III 606: L 654-55. This, though, is not to say that he abandoned the Aristotelian philosophy

altogether. Perhaps this moment is best seen as the point at which Leibniz embarked on the project of reconciling Aristotle with the Moderns. For an account of his early dealings with the mechanical philosophy, see Mercer, *Leibniz's Metaphysics.*

1 The earliest evidence is in a letter Leibniz wrote to his mentor Jakob Thomasius on 16/26 February, 1666, where Leibniz discussed a question raised by Thomasius as to why Anaxagoras spoke of the possibility of black snow, and showed some acquaintance with mechanist doctrines of perception. See A II.i 4-5. In *De arte combinatoria* of r666, there are a number of references to Hobbes' materialistic tract *De coipoie,* and a brief discussion of atomistic explanations, with reference to the atomistic tracts of Gassendi and J. C. Magnenus. See A VI.i 178, 183, 194, 216. In the theses for public disputation that Leibniz added to the work, he also included a claim that the four Aristotelian primary qualities, hot, cold, dry, and moist, could be reduced to density and rarity, in the style of the earlier seventeenth-century mechanist, Sir Kenelm Digby; see A VI.i 229, and Digby *Two Treatises in the one of which the Nature of Bodies in the other the Nature of Mans Soule is looked into in the way of discovery of the Immortality of Reasonable Soules* (Paris, r 644) bk. I, chap. Ill—IV. Leibniz's theological writings from the years immediately following also show an acquaintance with and a sympathy for the new mechanical philosophy. For example, in the *De transubstantiatione* (ca. 1668), Leibniz works within a framework within which the actions of mind are thought, and those of body are motion; see A VI.i 508-21: L 1x5-18). In the important *Confessio naturae contra atheistas* (1669), Leibniz gives an explicit endorsement of the mechanist program; see A VI.i 489: L I09-X0.

8 See Garber, "Motion and Metaphysics in the Young Leibniz," in Hooker, ed., *Leibniz: Critical and Interpretative Essays;* Mercer, *Leibniz's Metaphysics;* and chap. 3 in this *Companion.* God's continual recreation of the world was the basic premise in one of the important arguments for occasionalism; see Garber, "How God causes Motion: Decartes, Divine Sustenance, and Occasionalism," pp. 567-80. Oddly enough, Leibniz identifies this as "a view that has never been heard of until now" (A II.i 23-24: L 102), suggesting that he was not well acquainted with the Cartesian literature. Leibniz's reaction to the doctrine of occasionalism will be discussed at greater length below in sec. 4.4.

9 See chap. 4 in this *Companion.*

xo This is the main theme of Mercer, *Leibniz's Metaphysics.*

11 The notes are found in A Vl.ii 157-218; the HPN and TMA are found in that same volume. The HPN and TMA are also found in GM VI and G

IV, though there are some confusing differences in the numeration of the sections. The alternative title "Theoria motus Concreti" is not found on the title page of the HPN, but on the first page of the text.

12 For a fuller account of these writings, see Hannequin, *La première philosophie de Leibnitz,* vol. II, pp. 17-224, esp. pp. 59-148.

13 Loemker's otherwise fine translation should be treated with extreme caution in these passages. Leibniz is here especially indebted to Hobbes. See Kabitz, *Die Philosophie des jungen Leibniz* and Bernstein, *"Conatus,* Hobbes, and the Young Leibniz," pp. 25-37.

14 The account of collision is given on A Vl.ii 268: L 142, sects. 20-24; the consequences are presented in a series of theorems that immediately follow (not translated in L).

15 According to Descartes' conservation principle, the sum over all bodies of size times speed (quantity of motion) is a quantity conserved by God; see Descartes, *Principles of Philosophy,* pt. II, sec. 36. For a discussion, see Garber, *Descartes' Metaphysical Physics,* chap. 7. It should be noted here that Descartes' principle differs from the conservation of momentum. Momentum is a vector quantity, size (mass) times *velocity,* and change of direction entails a change in momentum, even if the speed remains the same. Not so for Descartes' quantity of motion, which remains the same even if the direction is changed. Leibniz rejects Descartes' principle of the conservation of quantity of motion, though he adheres to a principle of the conservation of momentum; see sec. 4.3.

16 Descartes' creation story can be found in chap. 7 of *Le monde,* and in his *Principles,* pt. Ill, sec. 46. These two accounts differ somewhat; the initial state of the world in *Le monde* is a complete chaos, while in the *Principles,* Descartes imagines God to have created particles of approximately equal size. In the opening of Pt. V of the *Discourse on the Method,* Descartes outlines the whole program of deriving the present state of the world from creation,· see Adam and Tannery, eds., *Oeuvres de Descartes,* VI 42ff.

17 For a more detailed discussion, see Hannequin *La première philosophie,* pp. 103-7.

18 Ibid., pp. 120-22.

19 For Wren's laws, see Wren, "Lex collisionis corporum," in *Philosophical Transactions of the Royal Society* (March 1669); they can also be found in Hall and Hall, eds., *The Correspondence of Henry Oldenburg,* vol. V, pp. 319-20 (Latin), 320-21 (English). Huygens' "Règles du mouvement dans la rencontre des corps" was published in the *Journal des sçavans,* 18 March 1669. It can also be found in *Oeuvres complètes de Christiaan Huygens,* vol. XVI, pp. 179-81. Huygens' main work on

bodies in impact was started as early as 1656, though not published until after his death; see "De motu corporum ex percussione," in *Oeuvres,* vol. XVI, pp. 29~r68. On Huygens see Dijksterhuis, *The Mechanization of the World Picture,* pp. 373-76. On Huygens and Wren, see Westfall, *Force in Newton's Physics,* pp. 146-57 (on Huygens), and 203-5 (on Wren).

20 See the discussion of Leibniz's doctrine of substance in this period in chap. 4 in this *Companion.* Occasionalism briefly seems to resurface later in the decade in the *Pacidius Philalethi* of October 1676; see C 6x7, 624-25.

2r For accounts of Leibniz's work in physics during this period see Belaval, "Premières animadversions de Leibniz sur les *Principes* de Descartes," in *Mélanges Alexandre Koyré v. II: L'aventure de l'esprit,* pp. 29-56; Fichant, "La 'réforme' leibnizienne de la dynamique, d'après des textes inédits"; Fichant, "Les concepts fondamentaux de la mécanique selon Leibniz, en 1676"; Fichant, "Neue Einblicke in Leibniz' Reform seiner Dynamik (1678)," pp. 48-68; and Robinet, *Architectonique disjonctive, automates systèmiques et idéalité transcendentale dans l'oeuvre de G. W. Leibniz,* chap. 5.

22 The text is also given, together with a valuable commentary, in Belaval, "Premières animadversions."

23 Belaval, "Premières animadversions," p. 46.

24 This seems to be a change from the earlier writings, including the early notes on Descartes, referred to above, which seem to have been written at roughly the same time. It also seems to differ from the position taken in the "Propositiones" of r672, where an important theme is that in the physics of the TMA, motion is lost in the world, unless there is a mind to add it; see A Vl.iii 66-68, 72. See also A Vl.ii 280.

25 Quoted in FC, p. LXIV. Unfortunately, Foucher de Careil gives no identifiable source for the quotation, and I have not been able to verify it in any more reliable source, so there is some uncertainty that attaches to the dating.

26 It is clear that this principle was much on Leibniz's mind as early as the mid-x670S; see A Vl.iii 490ff, from 1 April 1676, where Leibniz discusses the principle at some length. See the discussion in Fichant "Les concepts fondamentaux," pp. 228f.

27 This is an argument that Leibniz repeated often later; see the discussion in sec. 4.3.

28 This manuscript and its history are discussed in Fichant "La 'réforme' ", see also Robinet *Architectonique disjonctive,* chap. 5.5. Fichant plans to publish the manuscript as a whole, with commentary, though at the time of this writing, it has not yet appeared.

29 See Fichant, "La 'réforme'," p. 199, 202-3.

30 It is difficult to know when exactly Leibniz came to this conclusion. Fichant, "La 'réforme'," p. 207, emphasizes that in the important document of January 1678 where Leibniz first asserts the conservation of mv^2, the question of the nature of body is entirely untouched.

31 See note 37 for some bibliographical remarks on this work.

32 An outline written by Leibniz for a book on the elements of physics, which the editors of the Academy edition securely date at 1678-82 on the basis of watermark evidence, is indicative of the range of Leibniz's scientific interests at this time; see VE III 649-53 (L 277-80). It is difficult to identify all of the sketches from the period from 1679 to 1686 or so that might be relevant; much remains to be published, and of the notes on physics that are available, the dating is often very problematic. For some notes relating to Leibniz's interests in the foundations of physics that the editors of the Academy edition also date in the period 1678-82, see VE III 625-48; VE VII 1666-79; and VE VIII 2035-45. It should be noted that these papers include only material that the editors deem to be of philosophical interest; the more technical papers remain largely unedited.

33 The text is given in GM VI n7-119, together with a later manuscript appendix on pp. 119-23 (L 296-301). This was not Leibniz's first scientific paper in the 1680s. But it is fair to say that the "Brevis Demonstrado" marks the real beginning of Leibniz's attempt to make public his mature program for physics.

34 For accounts of the controversy, see especially litis, "Leibniz and the *Vis Viva* Controversy," pp. 21-35; Costabel, "Contribution à l'offensive de Leibniz contre la philosophie cartésienne en 1691-1692," pp. 264-287; and Costabel, *Leibniz and Dynamics.*

35 Leibniz claims not to have seen the full text of Newton's *Piincipia* until he arrived in Rome in April 1689, and claims to have seen only a review in the *Acta Eiuditorum* before that; see GM VI189 and GM VII 329. For Leibniz's first reactions to Newton's work, see Leibniz, *Marginalia in Newtoni Principia Mathematica* (1687), ed., Fellmann; Meli, *The Development of Leibniz's Techniques and Ideas about Planetary Motion in the Years 1688 to 1690;* and Meli, "Leibniz's Excerpts from the *Principia Mathematica,"* pp. 477-505. In *The Development,* p. 48ff Meli attempts to make the case that the set of Leibniz's notes on the *Principia* he discovered may date from before the Rome trip, casting some doubt on Leibniz's own account of his acquaintance with Newton's physics. But the argument looks indecisive to me, as "Leibniz's Excerpts," p. 478 suggests.

36 The text of the *Dynamica* was published for the first and only time in

GM VI 281-514. For a discussion of the Leibniz's plans to publish the book, see Robinet, *Architectonique disjonctive,* pp. 26r ff. Though the bulk of the work may have been completed in Italy, the prefatory "specimen" of arguments was probably written after January r69i; see AG 105-6.

37 The SD can be found in GM VI 234-54: AG r 17-38. Gerhardt's text has been superseded by a new edition, edited and translated into German by Dosch, Most, and Rudolph, where the editors give a text with a full apparatus criticus, and the text of a previously unpublished preliminary version of part I. The editors number the paragraphs in their text, and so references to the SD will be given by part and paragraph number; in this chapter references are also given to Gerhardt's text. It should be noted that only part I was published by Leibniz; part II was left in manuscript and only published after Leibniz's death. For an account of the composition of the SD, see Most, "Zur Entwicklung von Leibniz' *Specimen Dynamicum,"* pp. 148-163. Some of the most philosophically interesting content of the SD is repeated in an important essay dated May 1702, but unpublished in Leibniz's lifetime; see GM VI 98-106 or G IV 393-400: AG 250-256.

38 The text is given in GM VI r44-6i; a second (unpublished) version is given in GM VI r6i-87. For accounts of Leibniz's vortex theory, see Aiton, *The Vortex Theory of Planetary Motions;* Aiton, "The Mathematical Basis of Leibniz's Theory of Planetary Motion," pp. 209-25; and Meli, *The Development.*

39 Most notably smaller studies of the laws of motion (Costabel, *Leibniz and Dynamics* contains some such texts, and there are others in GM VI) and studies of optics in which Leibniz emphasizes that importance of reasoning from final causes. See especially "Unicum Opticae, Catoptricae, et Dioptricae Principium," *Acta Eruditorum,* June 1682, pp. 185-90; in Du III 145-51. Also, there are many technical papers on a wide variety of areas, including the barometer, chemistry, acoustics, magnetism, and clocks, as well as the papers that relate to the draining of the mines in the Harz Mountains. Excerpts are collected in vol. II pt. II of the Dutens edition of 1768 and in Gerland, *Leibnizens nachgelassene Schriften physikalischen, mechanischen und technischen Inhalts;* to the best of my knowledge, the transcription and publication of these manuscripts in the Academy edition is not yet even in progress.

40 On Newton's contribution in the Leibniz-Clarke exchange, see Koyre and Cohen, "Newton and the Leibniz-Clarke Correspondence," pp. *63-126.*

41 This sentiment is repeated often in this period and afterwards. See, for example, *Discourse on Metaphysics,* par. 10, G IV 434-45: AG 42-43; Correspondence with Arnauld (1686-90), G II, 58, 78, 98; "On the Cor-

rection of Metaphysics" (1694), G IV 470: L 433,· "On Body and Force, May 1702," GIV 393, 394-95, 398: AG 250, 251-52, 255; "Antibarbarus Physicus" (1710-16] G VII 343-44: AG 319.

42 See "On Body and Force, May 1702," GIV 394, 398: AG 251, 255 for this usage of the term "physics" and for the distinction between physics so understood and dynamics.

43 The threefold distinction I draw between mechanist physics proper, dynamics, or the science of force, and the metaphysical level of individual substance or monad corresponds reasonably closely to the account given in Gueroult, *Leibniz: Dynamique et Métaphysique,* pp. 203-8. Gale, "The Physical Theory of Leibniz," pp. 114-27, esp. p. 116 gives a different threefold categorization, distinguishing the metaphysical level (monads), the explanatory level (corporeal substance, primitive forces), and the observable level (body, derivative forces). McGuire, " 'Labyrinthus Continué: Leibniz on Substance, Activity, and Matter," in Machamer and Turnbull, eds., *Motion and Time, Space and Mattei,* pp. 290-326, esp. pp. 307Í gives a different threefold categorization still, distinguishing the levels of the ideal (space, time, motion), the phenomenal (phenomenal extension and change), and the real (substances and their attributes).

44 For a general account of Descartes' physics, see Garber, *Descartes' Metaphysical Physics.* For an account of physics among the Cartesians, see Mouy, *Le développement de la physique caitésienne: 1646-1712.*

45 For a good discussion of this argument, see Sleigh, *Leibniz and Arnauld: A Commentary on Their Correspondence,* pp. 112-14.

46 The exception to this rule is Gerauld de Cordemoy, who believed in both atoms and the void, but who considered himself to be a member of the Cartesian sect. The relevant texts can be found in Cordemoy, *Oeuvres philosophiques,* eds Clair and Girbal. See also Prost, *Essai sur l'atomisme et l'occasionalisme dans l'école cartésienne* and Battail, *L'avocat philosophe: Géraud de Cordemoy (1626-1684).*

47 For other occurrences of the same basic argument, see, for example, "Notes on Fardella, March 1690," FC, pp. 319-20: AG 103; "New System," unpublished draft (ca. 1694), G IV 473,· Response to Foucher (1695), G IV 492: AG 147; Letter to Jaquelot, 22 March 1703, G III 457; *Principles of Nature and Grace* (1714), par. i; *Monadology* (1714), pars. 1-2. This argument is discussed in more detail in Garber, "Leibniz and the Foundations of Physics: the Middle Years," in Okruhlik and Brown, eds., *The Natural Philosophy of Leibniz* pp.27-130, esp. sec. I.

48 See the account of the BD argument in sec. 4.3.

49 See the discussion of this argument in Gueroult, *Leibniz: Dynamique et Métaphysique,* pp. 46-49.

50 See also versions of the argument in Letter to the *Journal des Savants,* June 1691, GIV 464-65; letter to Antonio Alberti, 1691?, G VII447-48; SD, pt. I, par. io-ir; GM VI 2,40-41: AG 123-25; "On the Nature of Body and the Laws of Motion" (1690?), G VII 280-83: AG 245-50.

5 r See the account of this argument in Garber, "Leibniz and the Foundations of Physics," pp. 78-79.

52 See, for example, Descartes' *Principles,* pt. II, sees. 40-44, where Descartes sets out his account of impact. For a discussion of the notion of force in Descartes, see Garber, *Descartes' Metaphysical Physics,* chap. 9, as well as Gueroult, "The Metaphysics and Physics of Force in Descartes," and Gabbey, "Force and Inertia in the Seventeenth Century: Descartes and Newton," both in Gaukroger, ed., *Descartes: Philosophy, Mathematics and Physics,* pp. 196-229 and 230-320 respectively.

5 3 For a discussion of the notion of force in the earlier part of the century, see Westfall, *Force in Newton's Physics.*

54 A very similar account is given in "On Body and Force, May 1702"; see G IV 395: AG 252.

5 5 Leibniz is referring here to an example he used earlier in the essay, where he examines the behavior of a ball in a hollow tube when the tube is rotating around an external center.

56 On passive force in Leibniz, see Bernstein, "Passivity and Inertia in Leibniz's *Dynamics,"* pp. 97-113.

57 See "On Body and Force, May 1702," G IV 395: AG 252, where Leibniz makes the distinction more explicitly than he does in the SD.

5 8 Descartes is probably the first to have published the law that a body in motion remains in motion unless brought to rest by an external cause, though he was certainly not the first to have held it. See his *Principles,* pt. II, sees. 37-38, and Garber, *Descartes' Metaphysical Physics,* chap. 7. The principle, in fundamental opposition to Aristotelian physics, was characteristic of the new science of motion, and is found in many contemporaries and later figures. See, for example, Hobbes, *Leviathan,* chap. 2 (opening paragraph), and Spinoza, *Ethics,* pt. II, corollary to lemma 3 following prop. 13, and pt. Ill, prop. 6.

59 For a fuller development of this, see Garber, "Leibniz and the Foundations of Physics".

60 See Robinet, *Architectonique disjonctive,* where even finer distinctions are made.

61 See also Leibniz's comment to Bernoulli in his letter of 18 November 1698: "I hardly know how far the flint should be divided so that organic bodies (and therefore monads) might occur; but I readily declare that our ignorance on the matter has no effect on nature" GM III 552: AG 168.

62 But not without some difficulties. The bodies (matter) that unite with

the souls (forms) to form corporeal substances in the metaphysical writings are composed of further corporeal substances. But the matter that Leibniz identifies with primitive passive force in the SD cannot be construed in that way. For a discussion of this, see Garber, "Leibniz and the Foundations of Physics," sec. II.

63 For a fuller development of this strain in Leibniz's thought, see Garber, "Leibniz and the Foundations of Physics". See also Sleigh, *Leibniz and Arnauid,* and Wilson, *Leibniz's Metaphysics: A Historical and Comparative Study,* who also discuss extensively the notion of corporeal substance and the status of bodies on this conception.

64 For a fuller development of this conception of body in Leibniz, see Adams, "Phenomenalism and Corporeal Substance in Leibniz," in French, Uehling, and Wettstein, eds., *Contemporary Perspectives on the History of Philosophy,* pp. 217-57.

65 I take the simple substances in question to be the monads of the *Monadology.* See also letter to de Voider, 20 June 1703, GII251: AG 175-76.

66 See also letter to Nicolas Remond, ir February 1715, G III 636: L 659, where Leibniz makes a similar comment about the inertia of bodies, a derivative passive force.

67 The question of the possibility of there being real composite substance in a world of monads is discussed at some length in connection with the "substantial chain" or *"vinculum substantiale."* It is a matter of great controversy just how committed Leibniz was to the doctrine. The term *"vinculum substantiale"* first appears in Leibniz to Des Bosses, 5 February 1712, G II 435: AG 198, and appears regularly after that in their correspondence, though it seems not to appear outside of that exchange. On the *vinculum substantiale,* see Boehm, *Le "Vinculum substantiale" chez Leibniz. Ses origines historiques;* Fremont, *L'etre et la relation;* and Robinet, *Architectonique disjonctive.*

68 The Latin in Gerhardt reads: "Consistit in potentia activa et passiva primitivis . ..." Hence Loemker's translation: "It consists of active and passive power originally . ..." Given that primitive active and passive force (power) are well-established technical terms for Leibniz, it seems clear to me that "primitivis" is a mistake in the manuscript or a misprint in Gerhardt for "primitiva"; hence, the translation I give in the text.

69 This would raise a real problem for Leibniz, though; in his correspondence with de Voider, he emphasizes that we cannot have a derivative force without a corresponding primitive force. See, for example, letter to de Voider, 20 June 1703, G II 251: AG 176. Perhaps the primitive forces should also have appeared in Leibniz's characterization of semisubstances.

70 See Lennon, "Occasionalism and the Cartesian Metaphysic of Motion," pp. 29-40.

71 Clerselier to de la Forge, 4 December 1660, in Clerselier, *Lettres de M Descartes [tome III],* p. 642.

72 Cordemoy, *Oeuvres philosophiques,* p. 143.

73 Malebranche, *Recherche de la vérité* VI.II.III, in Malebranche, *Oeuvres,* éd., Rodis-Lewis, vol. I, p. 643: *The Search after Truth,* trans., Lennon and Olscamp, and *Elucidations of the Search after Truth,* trans., Lennon, p. 446.

74 Malebranche, *Oeuvres,* vol. I, pp. 643-46 (Lennon and Olscamp, pp. 446-48).

75 Malebranche, *Oeuvres,* vol. I, p. 649: Lennon and Olscamp, p. 450.

76 For a general discussion of Leibniz's rejection of occasionalism, see Brunner, *Études sur la Signification Historique de la Philosophie de Leibniz,* pp. 222-25 and Rutherford, "Natures, Laws, and Miracles," in Nadler, éd., *Causation in Early Modem Philosophy,* pp. 135-58.

77 For some important parts of the story, see Grant, "Place and Space in Medieval Physical Thought," in Machamer and Turnbull, *Motion and Time, Space and Matter,* pp. 137-67,· Grant, "The Condemnation of 1277, God's Absolute Power, and Physical Thought in the Late Middle Ages," pp. 2H-44; Grant, *Much Ado about Nothing: Theories of space and vacuum from the Middle Ages to the Scientific Revolution;* Duhem, *Medieval Cosmology,* ed. and trans., Ariew.

78 This position is strikingly held by Francesco Patrizi in the late sixteenth century, who was perhaps the first to step outside of the Aristotelian metaphysical framework and argue that space is neither substance nor accident, but *sui generis,* the container of all, God's first creation in which he placed all else, filling some places but leaving others empty. See Grant, *Much Ado,* pp. 199-206; Henry, "Francesco Patrizi da Cherso's Concept of Space and its Later Influence," pp. 549-75; Schmitt, "Experimental Evidence for and Against a Void: the Sixteenth-Century Arguments," pp. 352-66. Others, like Bruno, Telesio, and Campanella thought of space as a container independent of body, but never actually existing without body. See Grant, *Much Ado,* pp. 183-98.

79 See, e.g., Descartes' *Principles,* pt. II, sees. 5ff. See also the discussion in Garber, *Descartes' Metaphysical Physics,* chap. 5. An exception to this view among the Cartesians was Cordemoy; see the references cited in note 46.

80 For Gassendi's account of the vacuum, see his *Syntagma philosophicum,* pt. II, bk. II, chaps. 2-5, in his *Opera omnia,* vol. I. Much of the material, as it originally appeared in his earlier *Animadversiones in*

decimum librum Diogenis Laertii. . . can be found in a more easily digestible form in Charleton, *Physiologia Epicuro-Gassendo-Charltoniana,* bk. I chaps. 3-5. For further discussion, see Grant, *Much Ado,* pp. 207-10, Bloch, *La philosophie de Gassendi: Nominalisme, matérialisme et métaphysique,* pp. 194-200, and Joy, *Gassendi the Atomist.* Pascal's views are found in *Expériences nouvelles touchant le vide* of October 1647, and the *Récit de la grande expérience de l'équilibre des liqueurs* of October 1648, along with an important exchange of letters with Father Etienne Noël; these can be found in Pascal, *Oeuvres complètes,* éd., Lafuma, pp. 195ff. For further discussion of Pascal's views, see, e.g., Fanton d'Andon, *Horreur du vide: Expérience et raison dans la physique pascalienne,* and Guenancia, *Du vide à Dieu.* For a discussion of the confrontation between Descartes and Pascal on the vacuum, see Garber, *Descartes' Metaphysical Physics,* chap. 5.

81 Newton, *Principia,* bk. I, Scholium to dfn VIII.

82 Newton, *Principia,* bk. Ill, General Scholium.

83 For a very illuminating account of Newton on absolute space, see Stein, "Newtonian Space-Time," in Palter, ed., *The Annus Mirabilis of Sir Isaac Newton,* pp. 258-84.

84 In the important April 1669 letter to Thomasius, for example, Leibniz writes that "space is a primary extended being or a mathematical body, which contains three dimensions and is the universal locus of all things. ... So matter is a being which is in space or coextensive with space" A II.i 21: L 100.

85 See also Leibniz's account to Clarke as to how we acquire the concept of space, Leibniz's fifth letter, par. 47 (G VII 400-2:AG 337-39).

86 See also Leibniz to Des Bosses 29 May 1716, G II 515: AG 201. For more extensive discussions of Leibniz on space, see, e.g., Earman, "Was Leibniz a Relationist?," in French, Uehling, and Wettstein, eds., *Studies in Metaphysics,* pp. 263-76; Hartz and Cover, "Space and Time in the Leibnizian Metaphysic," pp. 493-519; and Wilson, *Leibniz's Metaphysics,* chap. 6.

87 See, e.g., Descartes, *Principles,* pt. II, sees. 16-19.

88 Leibniz seems to have a similar argument in mind in the SD of 1695; see SD, pt. II, par. 2, (GM VI 247-48: AG 130).

89 For a somewhat difficult exposition of this view, see "Conversation of Philarète and Ariste" (1712-15), Robinet, *Malebranche et Leibniz,* pp. 444-45 :AG 262.

90 The same argument is also echoed in the introduction to the *New Essays* (1704); see A VI.vi: RB 57. Note that the "First Truths" paper, usually thought to date from the early or mid-1680s has recently been redated to 1689 on the basis of watermark evidence. See VE VIII1998.

91 The same argument also comes up in the Leibniz-Clarke correspondence; see Leibniz's second letter, par. 2 (G VII 356: AG 322), Leibniz's third letter, par. 9, (G VII 365: AG 326), and especially Leibniz's fourth letter, Post Script (G VII 377-78: AG 332).

92 See Isaac Newton, *Principia Mathematica,* bk. I, scholium to the definitions.

93 Stein, "Newtonian Space-Time."

94 See also passages from earlier drafts of the SD given in the Dosch, Most, and Rudolph edition of the text, pp. 22-24, note to line 307 (AG 125, n. 173}, p. 58, note to line 288 (AG 136, n. 188), and p. 74. On the relation between Leibniz and Huygens on this issue, see Bernstein, "Leibniz and Huygens on the 'Relativity' of motion," pp. 85-102.

95 There is not space to examine Leibniz's arguments in detail here. For discussion of Leibniz's complex position and the various tangled arguments he offered for it, see Stein, "Some Philosophical Prehistory of General Relativity," in Earman, Glymour, and Stachel, eds., *Foundations of Space-Time Theories,* pp. 3-49, esp. pp. 3-6, with notes and appendices, and Bernstein, "Leibniz and Huygens".

96 This is translated in Stein, "Some Philosophical Prehistory".

97 I would like to thank Richard Arthur for correcting my translation here. On Leibniz's attempts to use his doctrine of the equivalence of hypotheses in connection with the issue of Copernicanism and the Church, see Meli, "Leibniz on the Censorship of the Copernican System," pp. 19-42.

98 For a discussion of Leibniz and relations, see chap. 5 in this *Companion.*

99 In a sketch from 1677, Leibniz suggested that since motion is not a property of bodies taken individually, it must be a property of the world as a whole; see VE III 654. In that passage, though, Leibniz notes that "motum non in se formaliter, sed ratione causae considerando, posse attribui eius corpori a cujus contactu provenit mutatio."

100 In a fragment from 1678-82, there is a suggestion that in at least the case where a human being - itself a corporeal substance, if anything is - is the seat of the force, we can determine which body is genuinely in motion through the effort felt. See VE VII 1673-74. But this is no help at all in the general case in physics.

101 This, I think, is at least a good part of what Russell had in mind when he made his celebrated comment about the relations between Leibniz's physics and metaphysics: "Leibniz has acquired much credit for the vaunted interconnection of his views in these two departments, and few seem to have perceived how false his boast really is. As a matter of fact, the want of connection is, I think, quite one of the weakest points in his system." Russell, *A Critical Exposition of the Philosophy of Leibniz,* p. 89; see also pp. 86-87.

102 See, e.g., Descartes, *Principles,* pt. II, sec. 36. For a fuller account of Descartes' conservation principle, see Garber, *Descartes' Metaphysical Physics,* chaps. 7 and 9.

103 Though there is not sufficient space to enter into the question here, it should be noted that Leibniz owes a considerable debt in his laws of motion to other thinkers of the period. For a more detailed account of Leibniz's borrowings, and the way in which he transformed the work of others, see Gueroult, *Leibniz: Dynamique et Métaphysique,* chap. 4·, Westfall, "The Problem of Force: Huygens, Newton, Leibniz," pp. 71-84, and Bos, "The Influence of Huygens on the Formation of Leibniz' Ideas," pp. 59-68.

104 For more detailed accounts of the complex disputes, see the references cited in note 34.

105 Leibniz outlines his strategy SD, pt. I, par. 15, (GM VI243-44: AG 127-28).

r06 See also the statement of the the principle of the equality of cause and effect in the body of the *Dynamica,* GM VI 437.

107 This is a paraphrase of the argument in the BD, GM VI117-19: L 296-98 and in *Discourse on Metaphysics,* par. 17 (G IV 442-43: AG 50). Gregory Brown, *" 'Quod ostendendum susceperamus':* What did Leibniz undertake to Show in the *Brevis Demonstration,"* pp. 122-37, correctly notes, against litis and Wilson, that it is the main point of the BD argument to show simply that force is distinct from quantity of motion, and not that mv^2 is what is actually conserved in nature. However, it is important to point out that elsewhere Leibniz uses the basic argument form for other purposes, as we shall see.

The point is a rather important one for Leibniz. Leibniz thinks that the Cartesian conservation law is grounded in a mistake about what the proper measure of force is. Leibniz thinks that people generally agree that force is conserved, but he thinks that the only force generally known was dead force, as treated in statics, for example, and this force is proportional to size times speed. See BD, GM VI117: L296; and SD, pt. I, par. 8, (GM VI 239AG 122-23).

r08 In the *Dynamica,* Leibniz argues for the conservation of the ability to do work (*potentia*) from the principle of the equality of cause and effect, both in the universe as a whole and in any closed system ("in quovis Systemate corporum cum aliis non communicantium"); see GM VI 440-41.

109 This argument is suggested in the opening paragraph of the BD, for example; see GM VIrr7:L296. It is important to remember here that the Cartesian quantity of motion, size times speed, is not the same as momentum, size (mass) times velocity, as discussed in this section.

The issue here is not the relatively trivial one as to whether one wants to take the conservation of living force, mv^1, or momentum as basic (though, as we shall later see, Leibniz does think that living force is more basic than momentum, whose conservation he also recognizes). Leibniz's point is that if the Cartesian law is satisfied, a system can lose the ability to do work; see the remarks to this effect in the SD, pt. I, par. 17, (GM VI 245-46: AG 129-30).

10 Such a machine is described, for example, in the *Specimen piaeliminare* to the *Dynamica,* GM VI 289-90: AG 108-9. In that place, Leibniz is concerned not only to show that quantity of motion differs from force, but that quantity of motion is not conserved; he gives three different *a posteriori* arguments to that conclusion. See GM VI288: AG 107 for a statement of the proposition proved, followed by three alternative demonstrations.

11 See Johann Bernoulli's comments to this effect in his letter to Leibniz, 8/18 June 1695, GM III 189.

12 Indeed, in the *Specimen praeliminare* of the *Dynamica,* he goes so far as to suggest that the equivalence of the two notions enables us to *demonstrate* Galileo's law of free fall! See GM VI292: AG in. Presumably what he has in mind is this. If the proper measure of force (the ability to do work) can be established *a priori,* then we can use the fact that in a given body, the force is proportional to the square of its speed to establish that the height to which a given body can raise itself then must be proportional to the square of its speed. From which it would follow by the principle of the equality of cause and effect that the speed it would acquire in free fall would be proportional to the square root of the distance fallen.

13 For more detailed discussions of the argument, see Gueroult, *Leibniz: Dynamique et Métaphysique,* pp 118-54, and Stammel, "Der Status der Bewegungsgesetze in Leibniz' Philosophie und die apriorische Methode der Kraftmessung," pp. 180-88. Gueroult, pp. 153-54 complains that were this argument to succeed (which he thinks it doesn't), then Leibniz would be in the position of holding that the conservation of mv^1 is necessary, in contradiction to his claim that the laws of motion are contingent, as we shall discuss below. This does not follow. What the argument would show, if successful, is that the proper measure of force is proportional to the square of speed. But the conservation of mv^1 requires the additional assumption that force is conserved in the world, an assumption that depends on the principle of the equality of cause and effect, which is contingent, for Leibniz, the result of God's wise choice.

14 Important here, of course is the work of Huygens and Wren; see the

references cited in note 19. Also important is the work of Mariotte; see his *Traité de la percussion ou choc des corps,* discussed in Westfall, *Force in Newton,* pp. 244-50.

115 Though note that Leibniz thought that in his account of impact, Malebranche fell prey to some of the same errors as Descartes did. See "Letter of Mr. Leibniz . . ." (1687), G III 53-54: L 352-53; Leibniz to Bayle, 9 January 1687, G III 46-47; and Mouy, *Les lois du choc d'après Malebranche.*

116 Descartes, *Principles,* pt. II, sees. 40-52. The measure of the "strength" of a body is implicit in the seven rules Descartes gives in sees. 46-52. For a discussion of Descartes' account of impact, see Gabbey, "Force and Inertia", and Garber, *Descartes' Metaphysical Physics,* chap.8.

117 Cf. litis, "Leibniz and the *Vis Viva* Controversy," p. 29.

n8 Leibniz himself identifies this as the first published version of the principle in SD, pt. II, par. 4, (GM VI 249-50: AG 133).

1x9 These are Descartes' first and second rules of impact; see *Principles,* pt. II, sees. 46, 47.

120 It should be noted that Loemker's'version of the diagram contains some mistakes. See also SD, pt. II, par. 4 (GM VI 249-51: AG 133-34).

121 For the sections of the *Dynamica* that relate to impact, see GM VI488-514; the ED is found in GM VI 215-31.

122 "Absolute force" is the terminology Leibniz uses in the principal exposition of the conservation law in the ED, rather than "living force," the term he uses in the SD, though in at least one place (p. 219), he does refer to it as "la Force vive absolûe". Leibniz also talks about the conservation of "motive action." This is treated somewhat separately in the important ED; see GM VI 22of, and the account in Gueroult, *Leibniz: Dynamique et métaphysique,* pp. 50-55. However, motive action seems to be what he calls simply "action" in the context of the *a priori* derivation of the conservation of mv^1 as discussed above, and in the ED it is lumped together with living force ("force totale absolue") in giving the equation that expresses the conservation of *mv"* law on GM VI227. And so, it will not get separate treatment here.

123 In the presentation in the ED, Leibniz measures the velocities with respect to the common center of gravity of the two bodies; see GM VI 226. But we should be able to take any reference point we like.

124 The principle is stated in the ED, GM VI 227; it is limited to elastic collisions on GM VI 330. The fuller argument is given in the *Dynamica;* for the definition of respective force, see GM VI 462; for the argument see GM VI 494-95, proposition ro. The argument I give in the text is a paraphrase of the first argument given in proposition 10. The device of the elastic cord connecting the two bodies is introduced

in the proof of proposition 7 on GM VI 492-93, where Leibniz argues that respective force depends only on the relative velocity of two bodies, not the direction.

125 This is exactly the situation treated in Descartes' fourth rule of impact, *Principles,* pt. II, sec. 49, where the smaller moving body rebounds from the larger body at rest after collision, keeping its speed.

126 The principle is stated in the ED, GM VI227,· the notion of common progress is differentiated from the Cartesian notion of quantity of motion on GM VI 216-17, and question of elasticity discussed on GM VI 230. The argument for the principle is given in the *Dynamica,* GM VI 496L

127 For an account of this feature of Leibniz's thought, see especially M. Wilson, "Leibniz's Dynamics and Contingency in Nature," in Machamer and Turnbull, eds., *Motion and Time, Space and Matter;* and Poser, "Aphorismus der Prinzipien und Kontingenz der Naturgesetze. Das Leibniz-Paradigma der Naturwissenschaft," pp. 164-179.

128 See sec. 5.1.

129 On Gassendi's atomism, see Bloch, *La philosophie de Gassendi: Nominalisme, matérialisme et métaphysique;* Brundell, *Pierre Gassendi, From Aristotelianism to a New Natural Philosophy;* Joy, *Gassendi the Atomist: Advocate of History in an Age of Science;* and Jones, *Pierre Gassendi 1592-1655: An Intellectual Biography.*

130 See *Principles,* pt. II, sees. 1-23. Descartes claims that in certain circumstances matter is actually divided into indefinitely small pieces in sees. 34-35·

131 For Boyle's attitude toward atomism, see his *Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666), in *The Works of the Honorable Robert Boyle,* ed., Birch, vol. 3, p. 137. The theoretical part can be found in *Selected Philosophical Papers of Robert Boyle,* ed., Stewart. On Boyle's attitude on the nature of the vacuum, see Shapin and Schaffer, *Leviathan and the Air-Pump,* chap. 2.

132 The argument is given in G VII 284-85, with some later reflections given on 285-88. As Leibniz discovered very quickly, the argument is not as straightforward as he originally thought, and to the best of my knowledge, this ingenious argument does not appear anywhere else in his writings.

133 On the role of elasticity in Leibniz's thought, see especially Breger, "Elastizität als Strukturprinzip der Materie bei Leibniz," pp. 112-21.

134 Breger, "Elastizität," p. 120 n. 40 also gives a reference to a manuscript from 1682-83 entitled: "Explicatio Mechanica Elastri.. .".

135 It is not clear here what Leibniz means by an illustration.

136 See, for example, Aristotle, *Physics* II.8; St. Thomas Aquinas, *De principiis naturae* IV.25. See also Wallace, *Causality and Scientific Ex-*

planation, vol. I, pp. 73-80.

137 *Principles,* pt. I, sec. 28. Note that this includes material from the French version. See also Meditation IV, Adam and Tannery, eds., *Oeuvres de Descartes* VII. 55.

138 *Ethics,* pt. I, appendix, Spinoza, *Opera,* ed., Gebhardt vol. II, pp. 78-80.

139 See, e.g., Gassendi's objection to Descartes, Adam and Tannery VII 308-9; and Robert Boyle, *Disquisitions on the Final Causes of Natural Things* (1688), in Boyle, *Works,* vol. V, pp. 392-444.

140 This would seem to be a consequence of Leibniz's claim that *"everything* in the world can be explained in two ways . ..", though it appears to lead to obvious theological difficulties about God as the final cause of evil.

141 A specific example Leibniz refers to on a number of occasions is the "Unicum Opticae, Catoptricae, et Dioptricae Principium," *Acta Eruditorum,* June 1682, pp. 185-90; in Du, III, pp. 145-51.

142 See Watson, *The Breakdown of Cartesian Metaphysics,* for an account of some of the seventeenth century debate about Cartesian minds and bodies.

143 Actually, this view was not Descartes', though it was that of many of his followers. See Garber, "Mind, Body, and the Laws of Nature in Descartes and Leibniz," pp. 105-133 for this and a fuller account of Leibniz's argument.

144 We should remember, though, an implicit limitation Leibniz imposes on mechanical explicability, insofar as he holds that perception cannot be given a mechanical explanation. See *Monadology,* par. 17, G VI 609: AG 215.

145 See, for example, Henry More, *The Immortality of the Soul,* in his *A Collection of Several Philosophical Writings* (London, 1662), and Sir Kenelm Digby, *Two Treatises* (Paris, 1644I. See also the discussion in Garber, "Soul and Mind," chap. V.i of *The Cambridge History of Seventeenth-Century Philosophy.*

146 On Leibniz's reception of More and Cudworth on these questions, see C. Wilson, *Leibniz's Metaphysics,* pp. i6off.

147 See the *Tentamen* and other works referred to in note 38.

148 See, e.g., Roger Cotes' introduction to the second edition of Newton's *Principia;* Newton, *Philosophiae naturalis principia mathematica,* eds., Koyre and Cohen, vol. I, p. 26. Leibniz gives this reading of Newton in a letter to Huygens, 1690, GM VI189:AG 309.

149 I would like to thank Christia Mercer and Nicholas Jolley for very helpful comments on an earlier version of this essay.

The Cambridge Companion to

LEIBNIZ

Edited by Nicholas Jolley
University of California, San Diego

CAMBRIDGE
UNIVERSITY PRESS

To the memory of Albert Heinekamp

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge CB2 1RP, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK http: //www.cup.cam.ac.uk
40 West 20th Street, New York, NY 10011-4211, USA http: //www.cup.org
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1995
Reprinted 1995, 1996, 1998

Typeset in Trump Mediaeval

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing-in-Publication Data is available

ISBN 0-521-36588-0 hardback
ISBN 0-521-36769-7 paperback

Transferred to digital printing 2004