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PHYSICS AND FOUNDATIONS

Daniel Garber

In our times, the domain of the physical sciences is reasonably well defined. Although, at its edges, the less empirically grounded parts of the physical sciences may merge into philosophical speculation, it is no compliment to a scientist to characterize his or her work as "philosophical." In this respect, we have moved a considerable distance from the early modern period. For many European thinkers in the sixteenth and seventeenth centuries, an account of the world around them was radically incomplete without a larger background picture in which to embed it, a picture that often included elements such as the basic categories of existence and the relation of the natural world to God. Many shared the sense of the interconnectedness of knowledge and felt the need for what might be called a foundation for the science that treats the natural world.

The project did not have precise boundaries, nor is it easy to characterize what it is that we are talking about when we are talking about the foundations of our understanding of the physical world. In many ways, the enterprise of providing foundations for a view of the physical sciences was shaped by two traditions, the Aristotelian tradition in philosophy and the Christian tradition in theology. As I shall argue in more detail, the Aristotelian tradition was a common element in the intellectual background of every serious thinker of the period and provided a model for what a properly grounded science should look like. Even for many of those who would reject the Aristotelian tradition in favor of other ancient traditions (such as atomism or Hermeticism) or other views of the world not obviously connected with ancient philosophical traditions, the Aristotelian tradition was hard to escape. But the Aristotelianism at issue was one deeply imbued with the spirit of Christian theology. From the time that Aristotelianism was introduced to the Latin West in the late twelfth and early thirteenth centuries, Christian doctrines about creation, divine omnipotence, and divine freedom put serious constraints on how Aristotelian doctrines were received. These constraints continued to play a role in how Europeans thought about the natural world throughout the period of the sixteenth and seventeenth centuries, and very often (though not always) entered into the versions of other non-Aristotelian philosophies proposed and adopted. Furthermore, the Christian God often provided an important resource in understanding the foundations of the natural world; for example, serving as the ultimate ground of the laws of motion for Descartes or the ground of absolute space for Newton. In this way, Christian theology and Aristotelian philosophy wind their ways throughout the questions that I will take up in this chapter.

FOUNDATIONS

It is tempting to frame the question of foundations in terms of physics and its metaphysical foundations,[1] but the question is somewhat more complex than that simple formulation would suggest.

In its strict Aristotelian meaning, metaphysics was usually taken to be the science of being qua being, the science of being as such. In addition, metaphysics was often taken to include an account of God, separated (i.e., immaterial) substances, and substance in general. Physics, on the other hand, was taken to be the study of natural things, things with natures, where natures were understood to be internal principles of motion and rest. Although the view that physics depends in some substantive way on metaphysics was not completely unheard of among medieval Aristotelian schoolmen, physics was generally held to be a discipline largely independent of metaphysics, and as a more concrete discipline dealing with sensible things, it should be studied *before* the student took up metaphysics. Therefore, in this strict sense, for an Aristotelian, one could not properly talk about the metaphysical *foundations* of physics.[2]

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[1] Historians who do include E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science: A Historical and Critical Essay* (London: Routledge and Kegan Paul, 1932); E. W. Strong, *Procedures and Metaphysics: A Study of the Philosophy of Mathematical-Physical Science in the Sixteenth and Seventeenth Centuries* (Berkeley: University of California Press, 1936); Alexandre Koyré, *Metaphysics and Measurement: Essays in Scientific Revolution* (Cambridge, Mass.: Harvard University Press, 1968); Gerd Buchdahl, *Metaphysics and the Philosophy of Science: The Classical Origins, Descartes to Kant* (Cambridge, Mass.: MIT Press, 1969); and Gary Hatfield, "Metaphysics and the New Science," in *Reappraisals of the Scientific Revolution*, ed. David Lindberg and Robert Westman (Cambridge: Cambridge University Press, 1990), pp. 93–166.

[2] For a discussion of the meanings of the term "metaphysics" among medieval Aristotelians, see John Wippel, "Essence and Existence," in *The Cambridge History of Later Medieval Philosophy*, ed. Norman Kretzmann, Anthony Kenny, and Jan Pinborg (Cambridge: Cambridge University Press, 1982), pp. 385–410, esp. pp. 385–92. On the question of ordering knowledge in late scholastic thought, see Daniel Garber, *Descartes' Metaphysical Physics* (Chicago: University of Chicago Press, 1992), pp. 58–62; and Roger Ariew, "Descartes and the Late Scholastics on the 'Order of the Sciences'," in *Conversations with Aristotle*, ed. Constance Blackwell and Sachiko Kusukawa (London: Ashgate, 1999). It should be noted that the term "metaphysics" as it was first used did not designate any discipline or subject matter. It was originally coined simply to designate the somewhat heterogeneous group of treatises that followed Aristotle's physical treatises in the ordering given in the edition of his writings by Andronicus of Rhodes. See G. E. R. Lloyd, *Aristotle: The Growth and Structure of His Thought*

But the view that metaphysics provides a kind of foundation for p indeed appear in the seventeenth century, most famously in the r ical physics of René Descartes (1596–1650) and Gottfried Wilhelr (1646–1716). As Descartes wrote in the preface to the 1647 Frenc of his *Principia philosophiae* (Principles of Philosophy, 1644): "The philosophy is like a tree. The roots are metaphysics, the trunk i and the branches emerging from the trunk are all the other scienc may be reduced to three principal ones, namely medicine, mech morals."[3]

In this case, it may therefore be proper to talk about the met foundations of physics. However, it is important to note that the cc of both metaphysics and physics at work here is somewhat idio very different from that found in the Aristotelian tradition or ever contemporary writers. For Descartes, for example, the study of b being that is at the center of Aristotelian metaphysics had no plac his philosophy.[4] What his philosophy did contain, on the other han account of how we acquire knowledge of the physical world, someth foreign to most other conceptions of metaphysics. Furthermore Descartes recognized no internal principles of motion and rest o that define the subject matter of physics for the Aristotelian schoo conception of physics was very different from theirs.

For Leibniz, too, the world of mechanist physics was grounded u both in metaphysical objects, simple substances or monads, and physical principles, the principles by virtue of which God chose to c world.[5] Although Leibniz's conceptions of metaphysics and physic a way, closer to the Aristotelian conceptions,[6] they were still distan from them (and from Descartes' conceptions of the domains) to r general comparison of the relation between metaphysics and phys lematic and unilluminating.[7] Problems with characterizing our qu

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[3] See René Descartes, *Oeuvres de Descartes*, ed. Charles Adam and Paul Tannery, new (Paris: CNRS/J.Vrin, 1964–74), 9B: 14. In quoting Descartes, I will generally follow the in *The Philosophical Writings of Descartes*, ed. and trans. John Cottingham, Robert Stootl Murdoch, and Anthony Kenny, 3 vols. (Cambridge: Cambridge University Press, 1984– this latter book is keyed to the Adam and Tannery edition, I will not give separate refer

[4] This has led Jean-Luc Marion to the bold (and somewhat paradoxical) conclusion that D not have a metaphysics. See Jean-Luc Marion, *On Descartes' Metaphysical Prism* (Chicag of Chicago Press, 1999), chap. 1. On Descartes' conception of metaphysics and physics a of knowledge, see Garber, *Descartes' Metaphysical Physics*, chap. 2.

[5] For a detailed development of this theme, see Daniel Garber, "Leibniz: Physics and Phi *The Cambridge Companion to Leibniz*, ed. Nicholas Jolley (Cambridge: Cambridge Uni 1995), pp. 270–352.

[6] As I discuss later in this chapter, Leibniz did recognize a sense in which the schoolmen say that bodies are composed of matter and form.

[7] Just how far the term "metaphysics" strayed from its earlier signification can be seen century, where in his *Discours préliminaire* (1751), d'Alembert characterized it as "the c physics of the soul"! See Jean Le Rond d'Alembert, *Preliminary Discourse to the Encycloped* [illegible]

terms of the metaphysical foundations of physics are compounded further by the fact that for many seventeenth-century students of nature, the term metaphysics did not come up at all, or if it did, it was explicitly rejected. Both Thomas Hobbes and Pierre Gassendi, for example, rejected the enterprise of metaphysics, strictly speaking.[8] Yet, in a number of such cases, as we shall see, they would certainly have acknowledged having views about the foundations of the physical world.

There are other ways in which the question of foundations came up in the seventeenth-century study of nature. For example, within the context of the Aristotelian system, mechanics, a "middle science" or branch of mixed mathematics, was distinguished from physics by virtue of the fact that whereas physics studies bodies insofar as they are natural and governed by internal principles of motion and rest, mechanics studies bodies insofar as they are constrained and made to do things that, left to their own natures, they would not do. In this context, mechanics makes use of some physical principles, such as the principle that heavy bodies tend to fall toward the center of the earth (which coincides with the center of the world in the Aristotelian system).[9] In this sense, one might say that physics is foundational with respect to mechanics. Similar points could be made about astronomy, optics, and harmonics, which are also branches of mixed mathematics. Furthermore, a number of figures drew distinctions between first causes and hidden natures on the one hand and phenomenal effects, their causal consequences, on the other. In his *Essay Concerning Human Understanding* (1690), for example, John Locke (1632–1704) famously distinguished between the real essence and the nominal essence. The real essence was the corpuscular substructure, the causal nexus from which flow the properties that make a body the body that it is, whereas the nominal essence was the collection of phenomenal properties accessible to our senses that result from that real essence, and in terms of which we sort bodies into categories.[10] Although this distinction between

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[8] Hobbes often spoke contemptuously of metaphysics; see especially Thomas Hobbes, *Leviathan; or, The matter, forme, & power of a commen-wealth ecclesiasticall and civill* (London: Andrew Crooke, 1651), chap. 46. However, in his own program for philosophy, following the logic, he does begin with what he called "first philosophy," which, for him, consisted of definitions. See Thomas Hobbes, *De corpore* (London: Andrew Crooke, 1655), pt. 2. Gassendi's posthumous *Syntagma philosophicum* in Pierre Gassendi, *Opera omnia*, 6 vols. (Lyon: Laurentius Anisson and Ioan. Baptista Devenet, 1658) also began with logic, but he moved directly from there into physics. Some of Descartes' followers also sidestepped their master's demand for metaphysical foundations and went directly into physics. See, for example, Henricus Regius, *Fundamenta physices* (Amsterdam: Ludivicus Elzevirius, 1646); and Jacques Rohault, *Traité de physique* (Paris: Charles Savreux, 1671).

[9] On the relation between mechanics and physics, see Domenico Bertoloni Meli, "Guidobaldo dal Monte and the Archimedean Revival," *Nuncius*, 7 (1992), 3–34; James G. Lennox, "Aristotle, Galileo, and 'Mixed Sciences'," in *Reinterpreting Galileo*, ed. William A. Wallace (Washington, D.C.: Catholic University of America Press, 1986), pp. 29–51; and Peter Dear, *Discipline and Experience: The Mathematical Way in the Scientific Revolution* (Chicago: University of Chicago Press, 1995).

[10] See John Locke, *An Essay Concerning Humane Understanding, in four books*, 3.6 (London: Printed by Eliz. Holt for Thomas Basset, 1690). One can find similar themes in other works of the period. See, for example, Robert Lenoble, *Mersenne ou La naissance du mécanisme*, 2nd ed. (Paris: J.Vrin, 1971), chap. 9; Tulio Gregory, *Scetticismo ed empirismo: Studio su Gassendi* (Bari: Laterza, 1961); Galileo

the phenomena and their underlying causes was usually drawn specifically in order to deny that we have any knowledge of those causes, it represented another way in which one could talk about the foundations of a science of the physical world. Also current, both in Aristotelian physics texts and in later non-Aristotelian texts, was a distinction between the general part of physics, which contained a general account of the contents of the physical world and the general principles that things follow, and the special part of physics, which treated the explanation of the behavior of specific kinds of bodies.[11] Again, this is another way of capturing the distinction between foundational questions and other questions in the science of body and in physics.[12]

For all these reasons, framing the question of foundations in terms of the metaphysical foundations of physics does not capture what is of interest. But although the question is difficult to formulate precisely, there is a real sense in which early modern practitioners of the sciences of body recognized and debated foundational questions related to the ground-level kinds of things that existed in the world, their natures, and their relations to God and spirit. In this chapter, I survey some sixteenth- and seventeenth-century conceptions of the foundations of the sciences of the physical world, understood in this broad and somewhat imprecise sense. I begin with an overview of the Aristotelian foundations and a brief survey of some of the alternatives to this conception of the world put forward by Renaissance thinkers. Then I discuss some foundational issues connected with the so-called mechanical philosophy that came to dominate the field by the end of the seventeenth century.

THE ARISTOTELIAN FRAMEWORK

Aristotle's philosophy, as developed by his medieval followers, was at the center of the school curriculum in the sixteenth century, as it was in the centuries before, and it remained central in the schools well into the seventeenth century. There were, of course, some significant variations between different schools and universities in different regions that corresponded to

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Galilei, *Istoria e dimostrazioni intorno alle macchie solari* . . . (Rome: Giacomo Mascardi, 1613), translated in Stillman Drake, *Discoveries and Opinions of Galileo* (Garden City, N.Y.: Doubleday, 1957), pp. 123 ff.

[11] In Eustachius a Sancto Paulo's enormously popular and often reprinted Aristotelian textbook, the *Summa philosophiae quadripartita* (Paris: Carolus Chastellain, 1609), the physics (one of the four parts of the book) is organized in this way. (My references are to the edition published in Cambridge by Rogerus Daniel in 1648.) The first part of the *Physica* deals with the "natural body in general." Part II then deals with inanimate bodies (the heavens, the earth, the elements, etc.), and the third treats animate things. Descartes' *Principia philosophiae* is similarly organized, with Part II treating "the principles of material things," Part III treating "the visible world" (i.e., the heavens), and Part IV treating specific kinds of bodies on earth, such as the magnet. Descartes died before he could complete two additional books on living things. One can find similar principles of organization in both Hobbes and Gassendi.

[12] One has to be a bit careful here. It is "science of body" and not "science of matter"; as we shall see, for an Aristotelian, matter, strictly speaking, is only one constituent of body, which also includes form.

different academic traditions and different religious persuasions (see Blair, Chapter 17, this volume).[13] But virtually all teachers, whether Catholic or Protestant, Northern or Southern European, could agree with the Jesuit *Ratio studiorum* (Plan of Studies) of 1586, their manual of instruction, in holding that, at least in the classroom, "in logic, natural philosophy, morals and metaphysics, the doctrine of Aristotle is to be followed."[14] Because this formed the basis of the education of virtually every literate person in early modern Europe, the works of Aristotle and, even more so, the numerous textbooks that gave accessible treatments of the Aristotelian philosophy offered a common vocabulary and conceptual framework with which to view the natural world.[15]

Natural philosophy, or physics, was generally defined by the schoolmen as the science of natural bodies (see Chapter 17, this volume). And so, for example, physics dealt with the natural fall of earthy bodies as their natures carry them toward the center of the universe. It was contrasted with the sciences of the artificial, such as mechanics, which dealt with ways of accomplishing goals that are contrary to the natures of things, such as when we use a lever or a pulley to raise a heavy body some definite distance.[16] As treated in physics, bodies (substances) were comprehended in terms of primary matter, substantial form, and privation. Primary matter was that which underlies change and persists when a body changes from one kind of thing to another. Substantial form, on the other hand, was that which characterizes a thing as the kind of thing that it is; it was what changed when a body became a thing of a different kind. In living things, the form was known as a soul. Privation was not really distinct from matter; it was the lack of some particular property in matter that allows that matter to acquire some property at a later time. In the strict Thomistic tradition, matter was pure potentiality and form pure actuality, and the one could not exist without the other. Scotist and Ockhamist traditions, however, gave form and matter more capacity for independent existence.[17]

For Aristotle, space was so closely connected with the body that occupies it that he denied the existence of empty space.[18] He wrote in the *Physics*: "Now it [space or place] has three dimensions, length, breadth, depth, the dimensions by which all body is bounded. But the place cannot *be* body; for if it were there would be two bodies in the same place. . . . What in the world, then, are we to suppose place to be?"[19]

The answer to this question is, evidently, "nothing," or at least nothing independent of the body that occupies it. If there were empty space, "how then will the body of the cube differ from the void or place that is equal to it? And if there can be two such things, why cannot there be any number coinciding?"[20] As a consequence, Aristotle rejected the idea of empty space as incoherent. Aristotle also used a number of arguments from the supposed incoherence of motion in a vacuum to argue for the impossibility of vacua in nature. By the thirteenth century, scholastic writers were beginning to attribute to nature a *horror vacui*, a kind of force by which nature resists allowing a vacuum to form.[21] However, Aristotle's medieval followers had some trouble with his doctrine of space and vacuum. One consequence was that without space outside of the (finite) world, not even God would seem to be able to move the universe, if he chose to do so. This apparent consequence of Aristotelian doctrine was rejected in the famous condemnation of Aristotle by Étienne Tempier, the bishop of Paris, in 1277: "[We condemn the proposition] that God could not move the heavens with rectilinear motion; and the reason is that a vacuum would remain."[22] As a result, scholastic Aristotelians had the difficult task of introducing the possibility of some kind of empty space into the universe without violating the basic principles of the Aristotelian philosophy.[23]

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[13] There are a number of different scholastic traditions within Aristotelian thought, as well as different humanist traditions. On this, see Charles Schmitt, *Aristotle and the Renaissance* (Cambridge, Mass.: Harvard University Press, 1983); and Roger Ariew "Descartes and the Scotists," chap. 2 of his *Descartes and the Last Scholastics* (Ithaca, N.Y.: Cornell University Press, 1999).

[14] S. J. Ladislaus Lukás, ed., *Ratio atque institutio studiorum* . . . (Rome: Institutum Historicum Societatis Iesu, 1986), p. 98. For a detailed discussion of the differences between sixteenth- and early seventeenth-century universities, emphasizing the centrality of Aristotle, see Richard Tuck, "The Institutional Setting," in *The Cambridge History of Seventeenth-Century Philosophy*, ed. Daniel Garber and Michael Ayers, 2 vols. (Cambridge: Cambridge University Press, 1998), 1: 14–23.

[15] For discussions of the burgeoning Aristotelian literature in the sixteenth and seventeenth centuries, see William Wallace, "Traditional Natural Philosophy," in *The Cambridge History of Renaissance Philosophy*, ed. Charles B. Schmitt, Quentin Skinner, and Eckhard Kessler with Jill Kraye (Cambridge: Cambridge University Press, 1988), pp. 201–35, esp. pp. 225 ff.; Charles B. Schmitt, "The Rise of the Philosophical Textbook," in Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 792–804; and Patricia Rief, "The Textbook Tradition in Natural Philosophy, 1600–1650," *Journal of the History of Ideas*, 30 (1969), 17–32.

[16] See Franciscus Toletus, *Commentaria una cum quaestionibus in octo libros de physica auscultatione* (Venice: Apud Iuntas, 1589), fol. 4v et seq.; Eustachius, *Physica*, in *Summa philosophiae quadripartita*, pp. 112–13; pseudo-Aristotle, *Mechanics*, 847a10 ff.

[17] Aquinas gives a lucid account of these notions and their relations in his essay "De principiis naturae," in Thomas Aquinas, *Opuscula omnia*, ed. P. Mandonnet, 5 vols. (Paris: Lethielleux, 1927), 1: 8–18, trans. Robert P. Goodwin in Thomas Aquinas, *Selected Writings of St. Thomas Aquinas* (Indianapolis: Bobbs-Merrill, 1965), pp. 7–28. For a different exposition of these notions, influenced by the later thought of William of Ockham and John Duns Scotus, see the *Physica* of Eustachius in his *Summa philosophiae quadripartita*, 1.1–1.3.

[18] See Edward Grant, *Much Ado about Nothing: Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution* (Cambridge: Cambridge University Press, 1981), chap. 1.

[19] Aristotle, *Physics*, 4.1 (209a 5–8, 14). Translations of Aristotle are taken from *The Complete Works of Aristotle*, ed. Jonathan Barnes, 2 vols. (Princeton, N.J.: Princeton University Press, 1984) 1: 355.

[20] Aristotle, *Physics*, 4.8 (216b 9–11), 1: 367.

[21] See Grant, *Much Ado about Nothing*, chap. 4, for a history of this notion.

[22] "Condemnation of 1277," para. 49, in Edward Grant, ed., *A Source Book in Medieval Science* (Cambridge, Mass.: Harvard University Press, 1979), p. 48. See also Grant, "The Condemnation of 1277, God's Absolute Power, and Physical Thought in the Late Middle Ages," *Viator*, 10 (1979), 211–44.

[23] See Grant, *Much Ado about Nothing*, chaps. 5–6; Pierre Duhem, *Medieval Cosmology: Theories of Infinity, Place, Time, Void, and the Plurality of Worlds*, ed. and trans. Roger Ariew (Chicago: University of Chicago Press, 1985), chaps. 5–6, 9–10.

These are the most general principles of the Aristotelian physical world. But also important was the Aristotelian doctrine of what specific bodies there are in the world. Within the sublunar world, the world below the sphere of the moon, there were four elements: earth, water, air, and fire. By virtue of the form it has, each of the elements had a characteristic array of what were generally called primary and motive qualities. The primary qualities were hot, cold, wet, and dry. Earth was cold and dry; water, cold and wet; air, hot and wet; and fire, hot and dry. In addition to the primary qualities, the elements had motive qualities, either heavy or light; earth and water, the heavy elements, had a tendency to fall downward toward the center of the world, and air and fire tended to rise and move away from the center of the world. Strictly speaking, however, these motive qualities derived from the fact that each of the elements had a proper place, with earth at the center, then water, air, and fire, respectively. When separated from that proper place, the elements had a tendency to move toward it.[24] In nature, however, the elements were rarely, if ever, found in their pure form. They were normally thought to be mixed together, giving rise to bodies that had properties different from those of the elements of which they were composed. The complex theory of mixtures gave rise to some of the most heated disputes in late medieval and early modern Aristotelianism (see Joy, Chapter 3, this volume).[25] Because things in the sublunar world were composed of different elements that were capable of separating, the sublunar world was a world of things in flux that were generated as the elements combined and corrupted as the elements separated.

Fundamentally distinct was the world of heavenly bodies. These bodies were made up not of the four elements but of a fifth element, the quintessence. Celestial physics was taken to be altogether different from terrestrial physics. Rather than moving in rectilinear paths, celestial bodies moved in perfect circles. Rather than a world of change, of generation and corruption, like the sublunar world, the celestial world was taken to be an unchanging world of physical perfection.[26]

Insofar as Aristotelianism represented orthodoxy, the overt rejection of this tradition constituted a touchstone of modernity; those who rejected the Aristotelian tradition were called "new philosophers" or "renovators" or "innovators" by their sixteenth- and seventeenth-century contemporaries. In the following sections, I survey a number of such figures and movements.

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[24] Compare the account in Eustachius, *Physica*, pp. 206–11.

[25] See also Anneliese Maier, *On the Threshold of Exact Science* (Philadelphia: University of Pennsylvania Press, 1982), chap. 6.

[26] For an account of medieval Aristotelian cosmology, see Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200–1687* (Cambridge: Cambridge University Press, 1994), esp. pt. 2.

RENAISSANCE ANTI-ARISTOTELIANISMS: CHYMICAL PHILOSOPHIES

Alchemy, chemistry, or, as some historians now prefer to refer to it, chymistry, goes back to ancient thought in one form or another (see Newman, Chapter 21, this volume).[27] But the sixteenth century was a time of particular interest in chymistry. The idea of chymistry meant many things to many people of the period, and it is very dangerous to generalize.[28] Chymistry was both theory and practice, involving both an account of at least a part of the natural world and an application of that understanding to the practical problems of transforming base metals into gold and silver. It also involved other aspects of what we might now call chemical engineering, as well as the problem of curing patients.[29] For some people, the theoretical part of chymistry dealt with only a part of nature, with mixtures or with metals.[30] But for others, chymistry was itself the whole of natural science, a genuine natural philosophy, and a conception of the foundations of natural science alternative to that offered by the Aristotelians insofar as chymical philosophers offered an alternative conception of the basic categories and principles of the physical world. In his popular and often reprinted *Traicté de la chymie* (Treatise on Chemistry, 1660), Nicaise Le Fèvre (1610–1669), for example, distinguished three sorts of chymistry: philosophical, medical, and pharmaceutical. But the first was for him the most important, the most basic. He wrote:

> [The first sort of chymistry is] wholly Scientifical and given to Contemplation, and may be very well termed *Philosophical*, having only its end in the knowledge of Nature, and of its effects; because it takes for object those on[l]y things which are constituted out of our power: So that this kinde of Chymical Philosophy, doth rest satisfied in the knowledge of the nature

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[27] For a survey of early chymistry, see Allen G. Debus, *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries*, 2 vols. (New York: Science History Publications, 1977), vol. 1, chap. 1; and William Newman, *Gehennical Fire: The Lives of George Starkey, an American Alchemist in the Scientific Revolution* (Cambridge, Mass.: Harvard University Press, 1994), chap. 3. Newman emphasizes especially the contributions of pseudo-Geber and Lull. Historiographical trends of the 1990s suggest that there is no substantive distinction between alchemy and chemistry in the period, and some have suggested using the archaic "chymistry" as a neutral term. I will follow that practice in this chapter. See Lawrence Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (Princeton, N.J.: Princeton University Press, 1998), pp. 8–10; William Newman and Lawrence Principe, "Alchemy vs. Chemistry: The Etymological Origins of a Historiographic Mistake," *Early Science and Medicine*, 3 (1998), 32–65.

[28] This is a point emphasized by Principe in *The Aspiring Adept*, pp. 214 ff.

[29] For a study of some of the practical aspects of chymistry focused on one particular practitioner, Johann Joachim Becher (1635–1682), see Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton, N.J.: Princeton University Press, 1994).

[30] For a discussion of the place of chymistry among the sciences, see, for example, Jean-Marc Mandosio, "Aspects de l'alchimie dans les classifications des sciences et des arts au XVIIe siècle," in *Aspects de la tradition alchimique au XVIIe siècle*, ed. Frank Greiner (Paris: S.É.H.A., and Milan: ARCHÉ, 1998), pp. 19–61.

> of the Heavens and Starres, the source and original of the Elements, the cause of Meteors, original of Minerals, and the way by which Plants and Animals are propagated. . . . We say then, that Chymistry makes all natural things, extracted by the omnipotent hand of God, in the Creation, out of the Abysse of the Chaos, her proper and adæquate object. . . . To make it short, It's nothing else but Physick, or knowledge of Nature it self, reduced to operation, and examining all its Propositions by reasons grounded upon the evidence and testimony of the senses.[31]

As such, chymistry aimed to replace the natural philosophy of the Aristotelians as taught in the schools. Le Fèvre went on to contrast the empty abstractions of the school philosophers with the down-to-earth and concrete approach of the chymists:

> If you ask from the School-Philosopher, What doth make the compound of a body? He will answer you, that it is not yet well determined in the Schools: That, to be a body, it ought to have quantity, and consequently be divisible; that a body ought to be composed of things divisible and indivisible, that is to say, of points and parts; but it cannot be composed of points. . . . [Le Fèvre continues with a long and somewhat comic rehearsal of the hesitations and uncertainties in the schoolman's answer.] You see then, that Chymistry doth reject such airy and notional Arguments, to stick close to visible and palpable things, as it will appear by the practice of this Art: For if we affirm, that such a body is compounded of an acid spirit, a bitter or pontick salt, and a sweet earth; we can make manifest by the touch, smell, taste, those parts which we extract, with all those conditions we do attribute unto them.[32]

Important to the chymical thought of the period was the work of Theophrastus Bombastus von Hohenheim, known as Paracelsus (1493–1541). Trained as a physician, he focused much of his writing on medical topics, where he opposed the authority of Galen and Aristotle in favor of an empirically based medicine that made extensive use of chymical remedies. But Paracelsus and his numerous followers were also associated with a more general intellectual reform, a philosophy of nature grounded in chymistry.[33]

As with other sixteenth-century reformers of natural philosophy, Paracelsus and his followers were motivated in good part by religious and theological

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[31] Nicaise Le Fèvre [Nicasius le Febure], *A Compleat Body of Chymistry* . . . (London: Thomas Ratcliffe, 1664), pp. 7, 9. Although French, Le Fèvre moved to London and became a member of the Royal Society of London. The book was originally published in French in 1660 but appeared quickly in English translation (1662), "Rendered into English by P. D. C. Esq. one of the Gentlemen of his Majesties Privy Chamber." It then came out in numerous editions in both French and English, with at least one German edition (1676). A fifth French edition came out as late as 1751.

[32] Le Fèvre, *A Compleat Body of Chymistry*, p. 10.

[33] The standard scholarly edition of Paracelsus's chymical and medical writings is Paracelsus, *Sämtliche Werke*, ed. Karl Sudhoff and William Matthiessen, 14 vols. (Munich: R. Oldenbourg, O. W. Barth, 1922–33). Collections of Paracelsus's writings in English include *The Hermetic and Alchemical Writings of Paracelsus*, ed. A. E. Waite, 2 vols. (Berkeley: Shambhala, 1976), and *Selected Writings*, ed. Jolande Jacobi, trans. Norbert Guterman (Princeton, N.J.: Princeton University Press, 1995).

questions.[34] Aristotle and Galen, heathen philosophers, were to be replaced by a genuinely Christian philosophy. For reformers of this sort, philosophy began with a return to the ancient wisdom found in the sacred scriptures, particularly the Old Testament, which predates the works of the pagan philosophers. But, at the same time, their chymical philosophy also turned to God's second book, the book of nature, for knowledge of the world. Peter Severinus (1540–1602), a late sixteenth-century follower of Paracelsus, famously advised those who seek wisdom to sell everything they owned, travel the world to observe what it contains, and then to build furnaces to probe its secrets (see Smith, Chapter 13, this volume).[35]

What emerged out of this study was a view of the world that was in some ways structurally similar to the Aristotelian world but in some ways radically different. According to Paracelsus, everything could be explained through three chymical principles, the *tria prima*: salt, sulphur, and mercury. (It is not altogether clear what the relation was between the *tria prima* and the Aristotelian four elements, nor what became of matter and form in the Paracelsian scheme.) For Paracelsus, everything was explicable chymically through combinations and transmutations of these principles. Indeed, even the creation story of Genesis could be interpreted chymically, as the successive separation of things from an initial *mysterium magnum* by way of chymical processes. In this way, the entire world was regarded as a vast chymical laboratory. Chymical transformations were driven by heat and fire, ultimately derived from the sun and from God himself. But the Paracelsian world was more than just chymistry. Also important to the chymical philosophy of Paracelsus were elaborate relations and harmonies among phenomena at all different levels, the macrocosm/microcosm analogy. In particular, Paracelsus held that the human being, the microcosm, is a representation of the universe as a whole, the macrocosm, and that there are thus systematic relations, reflections, and sympathies that hold between the two. This had important consequences for Paracelsian medicine and additionally for the practice of Paracelsian science. By virtue of these correspondences, the Paracelsian magus, through his own character and discipline, was capable of concentrating the celestial powers in himself and bringing about works. Hence, for the Paracelsian, science was not a neutral activity: The moral status of the philosopher had a central role to play in the enterprise. Furthermore, as with many other philosophies of the period, the world of Paracelsus's chymical philosophy was animated: Paracelsus saw the fire that was at the center of his philosophy as being, in some sense, equivalent to life itself.

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[34] My account of Paracelsus's views is drawn from the following sources: Allen G. Debus, *The Chemical Philosophy*, esp. vol. 1, chaps. 1–2; Debus, *Man and Nature in the Renaissance* (Cambridge: Cambridge University Press, 1978), esp. chap 2; and Brian Copenhaver and Charles B. Schmitt, *Renaissance Philosophy* (Oxford: Oxford University Press, 1992), pp. 306 ff.

[35] Cited in Debus, *Man and Nature*, p. 21.

Numerous works in chymistry followed the Paracelsian revival. Although there was considerable disagreement on detail, all agreed in seeing a certain small number of chymical principles and their combinations as essential to the project, and most shared a chymical cosmology and an interest in applying chymical ideas to medicine. Also important here was the importation into more traditional chymical theories of corpuscular ideas, in the sense that chymical elements were taken to be divisible to some smallest parts that retain their natures as elements. Main figures in the later chymical tradition include Severinus, Thomas Erastus (1524–1583), Daniel Sennert (1572–1637), Robert Fludd (1574–1637), Oswald Crollius (1560–1609), George Starkey (1628–1665), and Johannes Baptista Van Helmont (1579–1644).[36] Even a number of figures usually associated with the mechanistic strains of thought to be discussed later, such as Robert Boyle (1627–1691) and Isaac Newton (1642–1727), had serious interests in chymistry.[37]

The intellectual center of chymistry in the sixteenth and early seventeenth centuries was probably Germany; it was out of Germany that the Rosicrucians came, making a kind of religion out of their chymical philosophy.[38] But chymistry was also widespread in other European countries.[39] Chymists occupied a wide range of roles in society. Some taught in universities, particularly in faculties of medicine, and some worked at courts, particularly in the German-speaking countries. Many practiced chymistry as

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[36] Newman, *Gehennical Fire*, emphasizes the importance of corpuscular strains of seventeenth-century chymistry, which, he argues, derives from the thirteenth-century *Summa perfectionis* of pseudo-Geber. For a general survey of alchemy in the seventeenth century, see Debus, *Chemical Philosophy*, chaps. 3–7. For some studies of particular chymists of the period, see Newman, *Gehennical Fire* (a study of the American and English chymist George Starkey); Smith, *The Business of Alchemy*; Bruce Moran, *Chemical Pharmacy Enters the University: Johannes Hartmann and the Didactic Care of Chymiatria in the Early Seventeenth Century* (Madison, Wis.: American Institute of the History of Pharmacy, 1991); Bernard Joly, *Rationalité de l'alchemie au XVIIe siècle* (Paris: J. Vrin, 1992) (a study of Pierre-Jean Fabre); Hans Kangro, *Joachim Jungius' Experimente und Gedanken zur Begründung der Chemie als Wissenschaft* (Wiesbaden: Franz Steiner Verlag, 1968); Robert Halleux, "Helmontiana," *Academiae analectica, Koninklijke Academie, Klasse der Wetenschappen*, 45 (1983), 35–63; and Halleux, "Helmontiana II," *Academiae analectica*, 49 (1987), 19–36.

[37] For Boyle and chymistry, see Principe, *The Aspiring Adept*. For Newton, see Betty Jo Teeter Dobbs, *The Foundations of Newton's Alchemy; or, "The hunting of the greene lyon"* (Cambridge: Cambridge University Press, 1975); and Richard S. Westfall, "Newton and the Hermetic Tradition," in *Science, Medicine, and Society in the Renaissance*, ed. Allen G. Debus, 2 vols. (New York: Science History Publications, 1972), 2: 183–98.

[38] The classic work on this subject is Frances A. Yates, *The Rosicrucian Enlightenment* (London: Ark Paperbacks [Routledge and Kegan Paul], 1986; orig. publ. 1972).

[39] For accounts of the lively discussions over chymistry in seventeenth-century England and France, see Allen G. Debus, *The English Paracelsians* (New York: Watts, 1965); Allen G. Debus, *Science and Education in the Seventeenth Century* (New York: Science History Publications, 1970) (dealing with debates over chymistry in England); and Allen G. Debus, *The French Paracelsians* (Cambridge: Cambridge University Press, 1991). For discussions of chymistry in the Holy Roman Empire in the period, see Bruce Moran, *The Alchemical World of the German Court: Occult Philosophy and Chemical Medicine in the Circle of Moritz of Hessen, 1572–1632* (Sudhoffs Archiv, Beihefte 29) (Stuttgart: Franz Steiner Verlag, 1991).

a trade, either connected with medicine or with metallurgy and the like.[40] Chymistry remained, in one way or another, a part of the texture of much scientific thought throughout the early modern period.

RENAISSANCE ANTI-ARISTOTELIANISMS: THE ITALIAN NATURALISTS

Another group that set itself against Aristotle in the sixteenth century has come to be known as the Italian naturalists.[41] The rediscovery of Platonic texts in the fifteenth century presented European thinkers with a new way of looking at the world that was often at odds with the dominant Aristotelianism. The Latin translations of Plato by Marsilio Ficino (1433–1499), first published in 1484, were enormously popular. Included in Ficino's commentary on Plato's *Phaedrus* were translations of the neo-Platonist Proclus. Ficino's Latin translation of Plotinus appeared a few years later, in 1492.[42] The reintroduction of Plato and neo-Platonism into the intellectual world of the sixteenth century gave rise to a number of interesting new natural philosophies, including those of Girolamo Fracastoro (1470–1553), Bernardino Telesio (1509–1588), Girolamo Cardano (1501–1576), Francesco Patrizi (1529–1597), Giordano Bruno (1548–1600), and Tommaso Campanella (1568–1639).[43] These thinkers can also be construed as offering an alternative conception of the foundations of the physical world.

These natural philosophers shared a general scorn for Aristotelian natural philosophy, particularly its categories of matter and form.[44] At least three of these figures, Telesio in his *De rerum natura* (On the Nature of Things, 1563), Campanella in his *Universalis philosophiae, seu metaphysicarum rerum . . .*

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[40] I am indebted to conversations and correspondence with Tara Nummedal for information on her work about the chymist's life in German countries in the period. See Tara E. Nummedal, "Adepts and Artisans: Alchemical Practice in the Holy Roman Empire, 1550–1620," Ph.D. dissertation, Stanford University, Stanford, Calif., 2001. For the case of a chymist hanged for counterfeiting in France, see Adrien Baillet, *La vie de M. Descartes*, 2 vols. (Paris: Daniel Horthemels, 1691), 1: 231, and *Le Mercure françois; ou, la suitte de l'histoire de la paix*, 25 vols. (Paris: Iean and Estienne Richer, 1612–; this vol., 1633), 17: 713–23.

[41] The figures discussed in this section are often referred to as Renaissance philosophers of nature. The term, however, is a modern designation and now generally thought to be inappropriate. See Paul O. Kristeller, *Eight Philosophers of the Italian Renaissance* (Stanford, Calif: Stanford University Press, 1964), pp. 94–6, 110–12. For a general overview, in addition to Kristeller, see Copenhaver and Schmitt, *Renaissance Philosophy*, chap. 5; and Alfonso Ingegno, "The New Philosophy of Nature," in *The Cambridge History of Renaissance Philosophy*, pp. 236–63. My own accounts of these thinkers draw heavily on these sources.

[42] For details on the transmission of Platonic texts in the Renaissance, see Anthony Grafton, "The Availability of Ancient Works," in Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 767–91.

[43] Not all scholars link these philosophers to the strict Platonic tradition. See, for example, Frances Yates, *Giordano Bruno and the Hermetic Tradition* (Chicago: University of Chicago Press, 1964), who links Bruno to the Hermetic tradition.

[44] See Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 303 ff.

dogmata (Doctrines of the Universal Philosophy, that is, of Metaphysical Things, 1638), and Patrizi in his *Nova de universis philosophia* (New Philosophy of Everything, 1591), challenged Aristotelian conceptions of space and place and argued that space exists prior to everything and independent of body, an empty container that is, in part, filled by the physical world.[45] They also shared a view of the world as animate; as one study has eloquently characterized it, their world "was an enchanted world of ensouled objects linked together and joined to a higher realm of spirit and absolute being."[46] Writing in his *De sensu rerum et magia* (On the Sense of Things and on Magic, 1620), Campanella asserted that "the world is a feeling animal . . . [whose] parts partake in one and the same kind of life"; it posesses "a spirit . . . both active and passive in nature."[47]

However, in other respects, these natural philosophers differed considerably from one another. In his *De contagione* (On Contagion, 1546), Fracastoro saw attraction and sympathy, suitably interpreted in quasi-mechanistic and atomistic terms, as a basic phenomenon in nature.[48] For his part, Telesio rejected Aristotle's conception of body in terms of matter and form, replacing it with a conception of the world that is grounded in heat and cold, immaterial (but natural) agents that enter into lifeless matter and thereby animate it. According to Telesio, virtually everything that we see around us in the physical world is the result of a struggle between these two fundamental and immaterial agents, which oppose each other. Although Campanella began his career as a follower of Telesio,[49] in later years he came to think that Telesio's physical theory needed deeper grounding. He held that Telesio was wrong to think of hot and cold as natural agents and argued that their efficacy is traced back to God and the world soul.[50] In contrast, light formed the foundation of Patrizi's conception of the world in his *Nova de universis philosophia*. The notion of light was quite complex for Patrizi, who distinguished between the incorporeal light that emanates from God and other spirits and the corporeal light found in the physical world. For Patrizi, light of one sort or another explained everything in the physical world: life, the structure of the heavens, and the nature of an extracorporeal region where eternal beings can be found. Ultimately, light was grounded in God and a neo-Platonic hierarchy of being, beginning with The One. God was present at every level, working through the incorporeal element of light.[51] The views of others in this group, particularly Cardano and Bruno, are more difficult to characterize in a few words. Although Bruno was not altogether consistent as a thinker, there are a number of clear themes in his dense and complex writings. Bruno rejected the Aristotelian conceptions of God, substance, matter, and form. In *De la causa, principio, et uno* (On Cause, Principle, and Unity, 1584), he held that God is the only substance, and all finite things are just aspects of God. Bruno did hold, in a sense, that the main principles of body are matter and form. However, he often treated them as coinciding with one another in a very non-Aristotelian way.[52] Cardano's *De subtilitate* (On Subtlety, 1550) was a jumble of largely anti-Aristotelian views challenging various elements of the Aristotelian foundations of physics but obscure about what should replace them.[53]

None of these natural philosophers formed a lasting school or posed any serious danger to the reigning Aristotelianism of the schools. Their quest for novelty and originality may have undermined any serious attempt to form real traditions in a stable natural philosophy; they seem to have shared little more than a more or less animistic conception of the universe and a general sense that Aristotle had gotten it all wrong. Also important here was the fact that this philosophy never seemed to have any real institutional or professional home. Ficino was linked to the Medici court; Telesio had his own institute, the Accademia Cosentina, in the town of Cosenza, to promote his brand of natural philosophy; Patrizi was bishop of Gaeta; Fracastoro and Cardano were both physicians and taught medicine for at least a part of their careers; and Bruno and Campanella, both Dominicans, lived colorful lives that involved wandering through Europe disseminating their teachings and trying (unsuccessfully) to avoid getting into trouble with the authorities.

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[45] On conceptions of space and vacuum in sixteenth-century Italian thought, see Grant, *Much Ado about Nothing*, pp. 192–206. Although Telesio thought that a vacuum was possible and could be produced, he did not believe that it occurred naturally. See Charles B. Schmitt, "Experimental Arguments For and Against a Void: The Sixteenth-Century Arguments," *Isis*, 58 (1967), 352–66. More generally, on Telesio, see Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 309–14; Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 250–2; and Kristeller, *Eight Philosophers*, chap. 6. On Campanella, see Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 317–28; and Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 257–61, 294–5. On Patrizi, see Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 256–7; 292–3; and Kristeller, *Eight Philosophers*, chap. 7.

[46] Copenhaver and Schmitt, *Renaissance Philosophy*, p. 288. The passage continues: "A universal world-soul pervades all creatures and makes all creatures, even rocks and stones, alive and sentient in some degree. Stars and planets are mighty living divinities, so astrological bonds and forces of sympathy unify all things in the lower world under the rule of the higher; microcosm reflects macrocosm as man's lesser world mirrors the greater world of universal nature. Hidden symmetries and illegible signatures of correspondence energize and symbolize a world charged with organic sympathies and antipathies. The natural philosopher's job is to break these codes and uncover their secrets."

[47] Quoted in Brian Copenhaver, "Astrology and Magic," in Schmitt and Skinner, eds., *The Cambridge History of Renaissance Philosophy*, pp. 264–300, esp. p. 294.

[48] On Fracastoro, see Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 305–6.

[49] In his *Philosophia sensibus demonstrata* (Philosophy Demonstrated through the Senses, 1591), Campanella, like Telesio, rejected the form and matter of the Aristotelians; Telesio argued that body (mass) is animated by the manifest principles of heat and cold.

[50] See his *De sensu rerum et magia* (1620) and his *Universalis philosophiae, seu metaphysicarum rerum . . . dogmata* (1638). On Campanella, see the references cited in note 45.

[51] On Patrizi, see the references cited in note 45.

[52] On Bruno, see Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 314–17; and Hilary Gatti, *Giordano Bruno and Renaissance Science* (Ithaca, N.Y.: Cornell University Press, 1999).

[53] On Cardano, see Copenhaver and Schmitt, *Renaissance Philosophy*, pp. 308–9; *The Cambridge History of Renaissance Philosophy*, pp. 247–50; and Anthony Grafton, *Cardano's Cosmos: The Worlds and Works of a Renaissance Astrologer* (Cambridge, Mass.: Harvard University Press, 1999).

Their views were widely disseminated in Italy. But they were also well known in intellectual circles outside of Italy. Bruno's visit to England in 1583–5 had lasting effects; the influence of Italian philosophy can also be seen in the physics sketched out by Francis Bacon (1561–1626).[54] In France, Marin Mersenne (1588–1648) and Jean-Cecile Frey (ca. 1580–1631), defenders of the Aristotelian tradition in the 1620s, regularly listed Telesio, Bruno, and Campanella among their main opponents.[55] Pierre Gassendi (1592–1655), another anti-Aristotelian, seems to have borrowed from Patrizi's *Discussiones peripateticae* (Peripatetic Discussions, 1581) in his *Exercitationes paradoxicae adversus Aristoteleos* (Paradoxical Exercises against the Aristotelians, Part I, 1624, Part II published posthumously in 1658).[56] Later in the seventeenth century, these Italian neo-Platonists would constitute one of the important influences on the so-called Cambridge Platonists, including Henry More (1614–1687) and Ralph Cudworth (1617–1688).

RENAISSANCE ANTI-ARISTOTELIANISMS: MATHEMATICAL ORDER AND HARMONY

Behind many of the anti-Aristotelian views discussed in the last two sections lay another kind of foundational commitment, a commitment to the mathematical rationality and order of the world. In this view, which threads its way through chymical, Platonist, and other views, the world is governed by geometric and arithmetic structures. There are a number of different versions of this broadly Pythagorean view, which was concerned more with the large-scale structure of the cosmos than with the detailed analysis of matter. It is not surprising that this view became associated with music and the idea that nature is to be understood in terms of notions such as harmony. It must be remembered here that in the early seventeenth century, music was one of the middle sciences, along with astronomy, optics, and mechanics (see Andersen and Bos, Chapter 28, this volume). Traditional music theory dealt largely with numerical proportions, which were correlated with the notes of the scale and, in appropriate combinations, led to consonances. In this way, music was a science that dealt with harmony and order, both in the narrow sense of interest to practicing musicians and in a broader sense, in which it was of interest to natural philosophy.

For the English natural philosopher Robert Fludd, who was also very much a partisan of the chymical philosophies, a fundamental analogy for understanding the world was musical.[57] In one version, given in his *Utriusque cosmi maioris scilicet minoris metaphysica, physica atque technica historia* (The Physical, Metaphysical, and Technical History of Both Cosmoses, Namely the Greater and the Lesser, 1617–21),[58] Fludd's image of the world was based on the monochord, a string stretched between two bridges that was widely used in theoretical studies of music (see Figure 2.1). He pictured the cosmos as a monochord, with one end of the string anchored at the center of the Earth, and the other in the heavens. The sun is placed squarely at the middle of the string, dividing the string into two octaves. The notes of the scale (A, B, C, etc.) then mark out different regions of the cosmos, both subsolar and supersolar. Another more geometrical rendering of the same basic cosmology is given in Figure 2.2. This representation introduces two pyramids, which Fludd calls the material pyramid and the formal pyramid. The actual sounding music of the world results from an interaction between the two.[59]

For Athanasius Kircher (1601–1680), German by birth but a long-time professor at the Jesuit Collegio Romano in Rome, who also dabbled in chymistry, among many other pursuits, the cosmos was more like an organ[60] (see Figure 2.3). Instead of Fludd's one level of being, represented by the monochord, in his *Musurgia universalis* (Universal Harmony, 1650), Kircher recognized ten, which he likened to stops in an organ. The first six represented the results of the six days of creation; the remaining four dealt with other aspects of the world. When God, the divine organist, had pulled out all the stops, the world was then constituted. Each of these stops, of course, involved numerical proportions – harmonies – which blended together to produce the harmonies of the world as a whole. Within each rank, Kircher presented a vision of the harmonies at work. So, for example, at the level of cosmology, he argued for a conception of a harmony manifested in the relations each planet held with respect to the others, the whole relationship being governed by the sun.

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[54] See Graham Rees, "Bacon's Speculative Philosophy," in *The Cambridge Companion to Bacon*, ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996), pp. 121–45.

[55] See, for example, the (unpaginated) preface to Mersenne's *Quaestiones . . . in Genesim* (Questions on Genesis, Paris: Sebastian Cramoisy, 1623). On Mersenne's relations with Italian naturalism, see Lenoble, *Mersenne*, chap. 3. Jean-Cécile Frey attacks them in his *Cribrum philosophorum qui Aristotelem superiore et hac aetate oppugnarunt* (A Sieve for Philosophers Who Oppose Aristotle Both in Earlier Times and in Our Own, 1628) in his posthumous *Opuscula varia* (Various Works, Paris: Petrus David, 1646), pp. 29–89. On Frey, see Ann Blair, "The Teaching of Natural Philosophy in Early Seventeenth-Century Paris: The Case of Jean Cécile Frey," *History of Universities*, 12 (1993), 95–158.

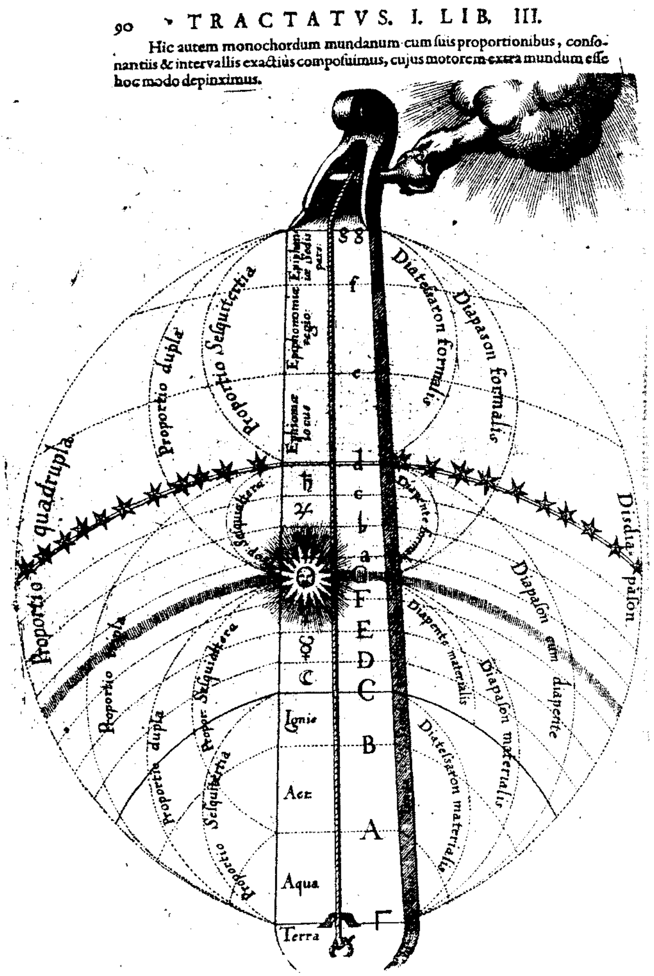
[56] On this, see pp. x–xi of Rochot's introduction to Gassendi, *Exercitationes paradoxicae adversus aristoteleos*, ed. and trans. [French] Bernard Rochot (Paris: J. Vrin, 1959).

[57] For accounts of Fludd's cosmology, see, for example, Robert Westman, "Nature, Art, and Psyche: Jung, Pauli, and the Kepler-Fludd polemic," in *Occult and Scientific Mentalities in the Renaissance*, ed. Brian Vickers (Cambridge: Cambridge University Press, 1984), pp. 177–229; and Eberhard Knobloch, "Harmony and Cosmos: Mathematics Serving a Teleological Understanding of the World," *Physis*, 32 (1995), 55–89. For an account of Fludd's chymical work, see Debus, *Chemical Philosophy*, chap. 4.

[58] Oppenheim and Frankfurt. "Technical" doesn't quite capture what Fludd has in mind here, which is the history with respect to its creation and construction.

[59] See Knobloch, "Harmony and Cosmos," p. 73.

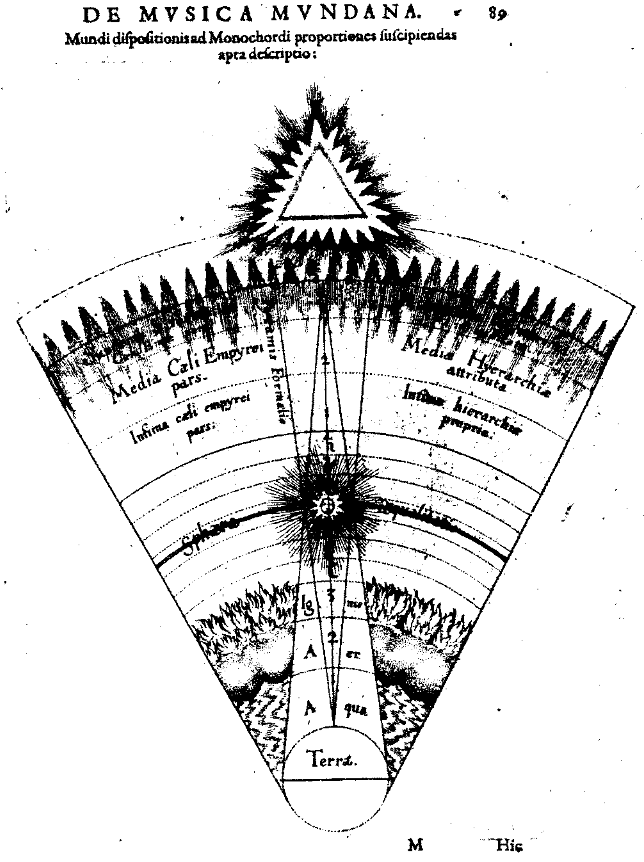
[60] For an account of Kircher's views, see Knobloch, "Harmony and Cosmos," pp. 76–82. For a brief overview of Kircher's connection to chymistry, see Claus Priesner and Karin Figala, eds., *Alchemie: Lexikon einer hermetischen Wissenschaft* (Munich: C. H. Beck, 1998), pp. 196–8.



90 TRACTATVS. I. LIB. III.

Hic autem monochordum mundanum cum ſuis proportionibus, conſonantiis & intervallis exactiùs compoſuimus, cujus motorem extra mundum eſſe hoc modo depinximus.

Figure 2.1. Representation of the cosmos in terms of a monochord. In Robert Fludd, *Utriusque cosmi maioris scilicet minoris metaphysica, physica atque technica historia*, 2 vols. (Oppenheim: Aere Johan-Theodori de Bry, typis Hieronymi Galleri, 1617–21), 1: 90. Reproduced by permission of the Rare Book Division, Department of Rare Books and Special Collections, Princeton University Library.



DE MVSICA MVNDANA. 89

Mundi diſpoſitionis ad Monochordi proportiones ſuſcipiendas apta deſcriptio:

Figure 2.2. Alternative representation of the cosmos in terms of interpenetrating pyramids. In Robert Fludd, *Utriusque cosmi maioris scilicet minoris metaphysica, physica atque technica historia*, 2 vols. (Oppenheim: Aere Johan-Theodori de Bry, typis Hieronymi Galleri, 1617–21), 1: 90. Reproduced by permission of the Rare Book Division, Department of Rare Books and Special Collections, Princeton University Library.

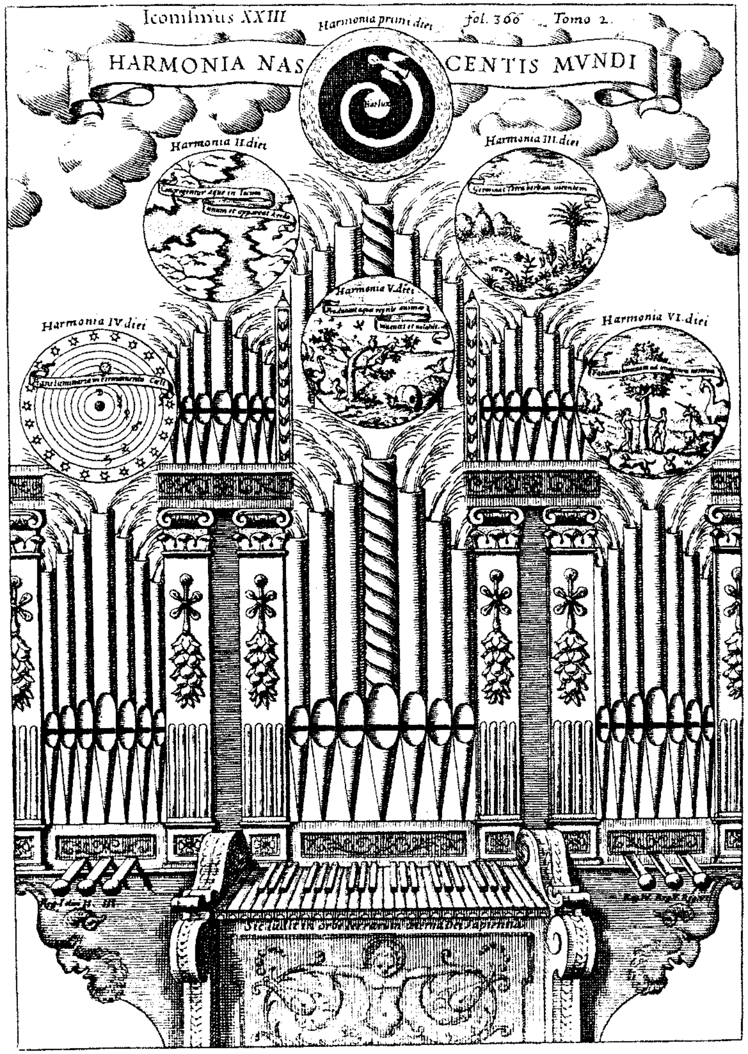


Figure 2.3. Representation of the cosmos in terms of an organ. In Athanasius Kircher, *Musurgia universalis, sive, Ars magna consoni et dissoni in X. libros digesta* . . ., 2 vols. (Rome: Haeredes Francisci Corbelletti, 1650), 2: 366. Reproduced by permission of the Rare Book Division, Department of Rare Books and Special Collections, Princeton University Library.

But the most interesting person in this group of Pythagoreans was the German astronomer and astrologer Johannes Kepler (1571–1630). Kepler was a technical astronomer well versed in the mathematical arcana of the subject, who knew how to construct an astronomical argument on the basis of observations. But just as interesting as the mathematical astronomy was a certain style of argument Kepler used that reveals an underlying view of the world that was in some ways similar to that of Fludd and Kircher.[61]

One of Kepler's best-known arguments was the explanation of why there are exactly six planets, including earth, and why they have the distances from one another that they do. In the *Mysterium cosmographicum* (The Mystery of the Universe, 1596; 2nd ed., with extensive notes, 1621), Kepler first argued that the distances among the planets, including earth, correspond to the distances one gets by nesting the five Platonic regular solids within one another: the tetrahedron (pyramid), cube, octahedron (formed by eight equilateral triangles), dodecahedron (12 pentagons), and icosahedron (20 equilateral triangles). Unfortunately, the world was not quite as simple as this model would suggest. Because the orbits of the planets turned out to be elliptical, as Kepler himself discovered, they did not fit this simple model, which implied circular orbits. However, Kepler was able to accommodate this within his model by regarding the elliptical orbit as a deviation from the circular orbit due to a magnetic attraction to or repulsion from the sun. For Kepler, this only showed an even greater rationality in the universe insofar as the deviations from the circular orbit give rise to pleasing celestial harmonies, literally a music of the spheres.[62]

Kepler also recognized harmonies in a broader sense – as correspondences among the different parts of the universe. For example, in arguing for Copernican cosmology in the *Epitome astronomiae copernicanae* (Epitome of Copernican Astronomy, 1618–21), Book IV, he compared the three regions of the Copernican cosmology – the central sun, the outer sphere of the fixed stars, and the intermediate region of the planets – with the Trinity. Kepler went on to compare the sun with the common sense in animals, located in the head, the globes that surround the sun with the sense organs, and the fixed stars with the sensible objects. He also compared the sun with the central fireplace and with the heart of the world, the seat of reason and life.[63] This is strongly reminiscent of the analogies drawn by Paracelsus and the chymical

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[61] For a detailed discussion of this aspect of Kepler's thought, see Bruce Stephenson, *The Music of the Heavens: Kepler's Harmonic Astronomy* (Princeton, N.J.: Princeton University Press, 1994). I am deeply indebted to Rhonda Martens for her help in understanding Kepler's views.

[62] See Johannes Kepler, *Epitome astronomiae copernicanae*, in Johannes Kepler, *Gesammelte Werke*, ed. W. von Dyck and M. Caspar, 20 vols. to date (Munich: C. H. Beck, 1937–), 7: 275, translated in *Epitome of Copernican Astronomy IV*, in *Ptolemy, Copernicus, Kepler* (Great Books of the Western World), ed. Robert Maynard Hutchins, 54 vols. (Chicago: Encyclopaedia Britannica, 1952), 16: 845–960, esp. p. 871.

[63] See Kepler, *Gesammelte Werke*, 7: 258–60, translated in Hutchins, ed., *Ptolemy, Copernicus, Kepler*, pp. 853–6.

philosophers between the macrocosm and the microcosm, whereby the cosmos in its structure reflects the human being and the human being reflects the larger world.

Kepler was, first and foremost, an astronomer who based his astronomical models on observation; indeed, the best observations obtainable. Kepler, of course, famously struggled to use the unprecedentedly accurate data of Tycho Brahe (1546–1601) in formulating his theory of the orbit of Mars. We must appeal to observation in order to determine the real motions of planets. In response to Fludd's fanciful symbolic representations of the cosmos, Kepler replied: "I have demonstrated that the whole corpus of tempered Harmonics is to be found completely in the extreme, proper motions of the planets according to measurements which are certain and demonstrated in Astronomy. To [Fludd], the subject of World Harmony is his picture of the world; to me it is the universe itself or the real planetary movements."[64]

But, for Kepler, observation alone was not enough to fix the real structure of the world: For that, we need to know that the structures discovered by observation correspond to a geometrical archetype. The discovery that the resulting model derived from observation satisfies an elegant geometrical schema permits assertions about the way the world really is. Kepler wrote in Book I of the *Epitome*: "Astronomers should not be granted excessive licence to conceive anything they please without reason: on the contrary, it is also necessary for you to establish the probable causes of your Hypotheses which you recommend as the true causes of Appearances. Hence, you must first establish the principles of your Astronomy in a higher science, namely Physics or Metaphysics."[65]

Mathematical harmonies had their role to play for Kepler, but only in tandem with observation. In this emphasis on observation as grounds for the claims about harmony, Kepler separated himself both from what Fludd had done and from what Kircher was yet to do.[66]

In many ways, Kepler's view of the basic nature of the cosmos agreed with elements of the worldviews of his contemporaries. Like that of many of his contemporaries, his universe was, in a sense, animistic. Kepler freely compared the sun with the intelligence of the world and with the heart of the world, and he compared the world with an animal and argued that the sun has a soul and is, in a sense, a living being.[67] However, from time to time he also used another, very different analogy. In a letter to Herwart von Hohenberg dated 10 February 1605, Kepler wrote:

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[64] Johannes Kepler, *Harmonices mundi libri V*, in *Gesammelte Werke*, 6: 376–7, quoted in Westman, "Nature, Art, and Psyche," p. 206.

[65] Kepler, *Gesammelte Werke*, 7: 25, quoted in Robert Westman, "Kepler's Theory of Hypotheses and the 'Realist Dilemma'," *Studies in History and Philosophy of Science*, 3 (1972), 233–64, esp. p. 261.

[66] On the controversy between Fludd and Kepler, see Westman, "Nature, Art, and Psyche"; Knobloch, "Harmony and Cosmos"; and Judith V. Field, "Kepler's Rejection of Numerology," in Vickers, ed., *Occult and Scientific Mentalities*, pp. 273–96.

[67] Kepler, *Gesammelte Werke*, 7: 259–60, 298 ff., translated in Hutchins, ed., *Ptolemy, Copernicus, Kepler*, pp. 855–6, 896 ff.

> My goal is to show that the heavenly machine is not a kind of divine living being but similar to a clockwork insofar as almost all the manifold motions are taken care of by one single absolutely simple magnetic bodily force, as in a clockwork all motion is taken care of by a simple weight. And indeed I also show how this physical representation can be presented by calculation and geometrically.[68]

This analogy leads us in the direction of a conception of the foundations of the physical world that is very different from the one that we have been considering so far, which came to be called the mechanical philosophy.[69] In radical contrast with the Renaissance world, infused with soul, sentience, intelligence, and harmony, the mechanical philosophy took as central the image of the machine.

THE RISE OF THE MECHANICAL AND CORPUSCULAR PHILOSOPHY

Many of the trends discussed in the previous sections persisted well into the seventeenth century and beyond, though sometimes in rather altered versions. However, there is another extremely important trend that emerged sometime in the sixteenth century and came to flourish in the seventeenth century: the mechanical (or corpuscular) philosophy.[70] The English natural philosopher Robert Boyle gave a particularly concise and cogent account of this position in his important essay *The Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666).

The mechanical philosophy, as Boyle presented it, replaced the explanation of the manifest properties of bodies in terms of the Aristotelian notions of form, matter, and privation, with a view in accordance with which those properties are "produced Mechanically, I mean by such Corporeall Agents, as do not appear, either to Work otherwise, then by vertue of the Motion, Size,

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[68] Kepler, *Gesammelte Werke*, 15: 146, quoted in Max Caspar, *Kepler* (London: Abelard-Schuman, 1959), p. 136.

[69] Insofar as it involves the magnet, arguably it does not get us all the way to a genuine mechanical conception of the world, where everything happens through size, shape, motion, and the impact of bodies on one another.

[70] Among contemporaries, the two names are virtually synonymous. The *Oxford English Dictionary* (q.v. mechanical) cites John Harris's *Lexicon Technicum* (1704) on this question: "*Mechanical Philosophy*, is the same with the Corpuscular, which endeavours to explicate the Phænomena of Nature from Mechanical Principles." Robert Boyle seems to identify the two in his *Of the Excellency and Grounds of the Corpuscular or Mechanical Philosophy* (1674). Calling it "corpuscular" emphasizes that the manifest properties of bodies are to be explained in terms of their smaller parts, and calling it "mechanical" emphasizes that the principles used in explanation are broadly mechanical. For histories of seventeenth-century science that emphasize the mechanical philosophy, see E. J. Dijksterhuis, *The Mechanization of the World Picture*, trans. C. Dikshoorn (Oxford: Oxford University Press, 1961); Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: John Wiley, 1971); and Marie Boas Hall, "The Establishment of the Mechanical Philosophy," *Osiris*, 10 (1952), 412–541.

Figure and Contrivance of their own Parts."[71] Boyle explicated this view in a number of basic theses: (1) "there is one Catholick or Universal Matter common to all Bodies, by which I mean a Substance Extended, divisible and impenetrable"; (2) "to discriminate the Catholick Matter into variety of Natural Bodies, it must have Motion in some or all its designable Parts"; (3) "Matter must be actually divided into Parts, . . . and each of the primitive Fragments . . . must have two Attributes, its own Magnitude . . . and its own *Figure* or *Shape*."[72] In this way, the mechanical or corpuscular philosophy rejected the explanation of physical phenomena in terms of Aristotelian forms and qualities, the innate tendencies of substances to behave in particular ways. It also sought to eliminate all sensible qualities from objects themselves; the Aristotelian's hot and cold, wet and dry, are eliminated as real qualities of things, as are sensible qualities such as color and taste. For the mechanical philosopher, everything, be it terrestrial or celestial, natural motion or constrained, must be explained in terms of the size, shape, and motion of the parts that make it up, just as the behavior of a machine is explained. As Descartes summarized the program:

> Men who are experienced in dealing with machinery can take a particular machine whose function they know and, but looking at some of its parts, easily form a conjecture about the design of the other parts, which they cannot see. In the same way I have attempted to consider the observable effects and parts of natural bodies and track down the imperceptible causes and particles which produce them.[73]

In this way, the image of the macrocosm and the microcosm, central to chymical philosophies and Renaissance naturalism, found its way into mechanism after a fashion. For the mechanical philosopher, as for the chymist and the Renaissance naturalist, what happens at one level reflects and is reflected by what happens at every other level.

Another important feature of the mechanist foundations of nature was laws of nature. The idea of natural law in the sense of moral laws governing human behavior decreed by God was founded long before the early modern period; it seems to be a direct extension of the notion of a law in the ordinary political sense.[74] But the idea that there are general laws that govern insentient and inanimate nature, mathematically formulable regularities that govern

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[71] Robert Boyle, *The Works of Robert Boyle*, ed. Michael Hunter and Edward B. Davis, 14 vols. (London: Pickering and Chatto, 1999–2000), 5: 302.

[72] Boyle, *Works*, 5: 305–307.

[73] René Descartes, *Principia philosophiae* (Amsterdam: Ludovicus Elzevirius, 1644), 4.203. For a discussion of some of the epistemological implications of this view, see Larry Laudan, "The Clock Metaphor and Hypotheses: The Impact of Descartes on English Methodological Thought, 1650–1670," in his *Science and Hypothesis* (Dordrecht: Reidel, 1981), pp. 27–58.

[74] For an account of natural law theories in the seventeenth century, see Knud Haakonssen, "Divine/Natural Law Theories in Ethics," in Garber and Ayers, eds., *The Cambridge History of Seventeenth-Century Philosophy*, 2: 1317–57.

all bodies, was an apparently new feature of the mechanical philosophy of the seventeenth century; with the idea that there is one kind of matter in the whole of the universe came the idea that there is one set of laws that governs that matter. Although perhaps not the first to have such an idea, Descartes was responsible for its first appearance in print in a self-conscious and foundational context. In his *Principia philosophiae*, Descartes announced "certain rules or laws of nature, which are the secondary and particular causes of the various motions we see in particular bodies."[75] The laws of nature in question are three laws governing the motion of bodies, including two laws governing the persistence of motion and a law governing collision. Although his laws were considerably debated, and alternatives were proposed by Huygens, Leibniz, Newton, and others, after Descartes, the idea that the world is governed by precise mathematical laws seemed to become a central part of the mechanist foundations of the physical sciences.[76]

Galileo Galilei (1564–1642) (along with his Italian followers) is generally credited with being one of the founders of the mechanist program in the early part of the century.[77] In Northern Europe, an atomist mechanist program was initiated in the 1610s by Isaac Beeckman (1588–1637), a somewhat itinerant schoolmaster in the Netherlands who was known to Descartes, Mersenne, Gassendi, and many other thinkers of the period.[78] By the late 1620s, this program had made its way to France and was being pursued by Mersenne,

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[75] Descartes, *Principia philosophiae*, 2.37. Descartes' laws were first announced as such in Chapter 7 of his *Traité de la lumière* (Treatise on Light, 1633), which remained unpublished until 1664, by which time the idea of laws of nature was firmly established. Galileo had presented what we would today call laws of motion, a version of the so-called law of inertia and the law of free fall, in his *Dialogo sopra i due massimi sistemi del mondo* (1632), in *Opere di Galileo Galilei*, ed. A. Favaro (Florence: Barbèra, 1890–1910), 7: 44–53, 173–5, translated in *Dialogue Concerning the Two Chief World Systems – Ptolemaic and Copernican*, trans. Stillman Drake (Berkeley: University of California Press, 1967), pp. 20–8, 147–9; and *Discorsi e dimostrazioni matematiche intorno a due nuove scienze* (Leiden, 1638), in *Opere di Galileo Galilei*, 8: 209 10, 243, translated with introduction and notes by Stillman Drake in *Two New Sciences: Including Centers of Gravity & Force of Percussion* (Madison: University of Wisconsin Press, 1974), pp. 166–7, 196–7. But aside from the problems of interpretation, particularly with respect to the so-called law of inertia, Galileo himself never characterizes these as "laws"; in his thought they have the character of regularities that govern heavy bodies in the vicinity of the centers toward which they are attracted. Francis Bacon talked about the forms that constitute particular qualities (heat, light, and weight, for example) as constituting laws in the sense that whenever the form or nature was present, the quality would be as well. See Bacon, *Novum Organum*, 1.17. But this seems to be a very different sense of law.

[76] For a general discussion of the idea of laws of nature in the seventeenth century, see J. R. Milton, "Laws of Nature," in Garber and Ayers, eds., *The Cambridge History of Seventeenth-Century Philosophy*, 1: 680–701.

[77] The literature on Galileo is enormous, and the main aspects of his career are well known. For a survey of some aspects of this question with respect to Galileo, see Peter Machamer, "Galileo's Machines, His Mathematics, and His Experiments," in *The Cambridge Companion to Galileo*, ed. Peter Machamer (Cambridge: Cambridge University Press, 1998), pp. 53–79.

[78] Beeckman's notebooks, which include records of his conversations with Descartes, for example, are published as *Journal tenu par Isaac Beeckman de 1604 à 1634*, ed. Cornelis de Waard, 4 vols. (The Hague: Martinus Nijhoff, 1939–53). For an account of his life and thought, see Klaas van Berkel, *Isaac Beeckman (1588–1637) en de Mechanisering van het Wereldbeeld (with a summary in English)* (Amsterdam: Rodopi, 1983).

Gassendi, Gilles Personne de Roberval (1602–1675), Thomas Hobbes (1588–1679), and Kenelm Digby (1603–1665), the last two visiting from England.[79] Descartes took his version of it to the Netherlands starting in the late 1620s.[80] Although he was not uncontroversial there, Descartes had many Dutch followers, including a number in the universities.[81] The program even had some success in Germany, though Germany was intellectually more conservative than Western Europe.[82] There was a tradition of atomism in England that went back to the early part of the century, but it was given new life with the introduction of Cartesian and Gassendist ideas at mid-century.[83] By the 1660s or 1670s, mechanist approaches to nature were found virtually throughout Europe and seem to have dominated intellectual discourse. By and large, the mechanical philosophy flourished outside the universities, first in salons and private academies, such as Mersenne's academy in Paris and the Montmort academy that followed it, and then in institutions such as the Royal Society of London and the Académie Royale des Sciences in Paris.[84] But the philosophy also found some success in the educational institutions in the Netherlands, France, and even Germany.[85]

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[79] On Mersenne, see Robert Lenoble, *Mersenne ou La naissance du mecanisme* (Paris: J. Vrin, 1971). For the diffusion of Gassendi's thought in Europe, see *Gassendi et l'Europe*, ed. Sylvia Murr (Paris: J. Vrin, 1997), pt. II. On Hobbes, see F. Brandt, *Hobbes's Mechanical Conception of Nature* (Copenhagen: Levin and Munksgaard, 1928).

[80] For the diffusion of Cartesian thought, the best general reference is still Francisque Bouillier, *Histoire de la philosophie cartésienne*, 3rd ed., 2 vols. (Paris: Delagrave, 1868). On the reception of Cartesian ideas in Italy, see Giulia Belgioioso, *Cultura a Napoli e cartesianesimo* (Galatina: Congedo editore, 1992).

[81] See Theo Verbeek, *Descartes and the Dutch: Early Reactions to Cartesianism (1637–1650)* (Journal of the History of Philosophy Monograph Series) (Carbondale: Southern Illinois University Press, 1992).

[82] See Francesco Trevisani, *Descartes in Germania: La ricezione del cartesianesimo nella facoltà filosofica e medica di Duisberg (1652–1703)*, (Milan: Franco Angeli, 1992); and Christia Mercer, *Leibniz's Metaphysics: Its Origins and Development* (Cambridge: Cambridge University Press, 2001).

[83] On atomism in England, see Robert H. Kargon, *Atomism in England from Hariot to Newton* (Oxford: Oxford University Press, 1966). On Cartesianism in England, see Alan Gabbey, "Philosophia Cartesiana Triumphata: Henry More (1646–1671)," in *Problems of Cartesianism*, ed. T. M. Lennon, J. M. Nicholas, and J. W. Davis (Kingston and Montreal: McGill-Queens University Press, 1982), pp. 171–249.

[84] On the Royal Society of London, see, for example, Michael Hunter, *Establishing the New Science: The Experience of the Early Royal Society* (Woodbridge: Boydell Press, 1989). On the Mersenne circle, the Montmort academy, and the Académie Royale des Sciences, see Harcourt Brown, *Scientific Organizations in Seventeenth-Century France (1620–1680)* (Baltimore: Williams and Wilkins, 1934); Frances A. Yates, *The French Academies of the Sixteenth Century* (London: Routledge, 1988; orig. publ. 1947), chap. 12; Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1803* (Berkeley: University of California Press, 1971); Alice Stroup, *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences* (Berkeley: University of California Press, 1990). On the Cartesian salons in Paris, see Erica Harth, *Cartesian Women* (Ithaca, N.Y.: Cornell University Press, 1992).

[85] See Verbeek, *Descartes and the Dutch*; Trevisani, *Descartes in Germania*; Mercer, *Leibniz's Metaphysics*; and Laurence Brockliss, "Les atomes et le vide dans les collèges de plein-exercice en France de 1640–1730," in *Gassendi et l'Europe*, ed. Sylvia Murr (Paris: J. Vrin, 1997), pp. 175–87. Interesting in this connection is a battle between the older Aristotelians and the younger Cartesians on the faculty of the Université d'Angers in the early 1670s. On this, see Roger Ariew, "Cartesians, Gassendists, and Censorship," chap. 9 of his *Descartes and the Last Scholastics*. Cartesianism seems to come somewhat

When Boyle introduced the general principles of the mechanical philosophy, he quite explicitly put aside differences among different sects, claiming to write "rather for the Corpuscularians in general, than any party of them."[86] But one can find among practitioners who identified themselves as mechanical philosophers or were identified by their contemporaries as mechanical philosophers a variety of different conceptions of the worldview that underlies the world of corpuscles in collision. In the sections that follow, I discuss some of the important variants of the mechanical philosophy.

THE MECHANICAL PHILOSOPHY: THEORIES OF MATTER

An important aspect of the foundations of physics was the conception of the nature of matter, the stuff of which the physical world is ultimately made. In the mechanical philosophy, one important strand of thinking about the nature of matter was the revival of ancient atomism.[87] When looking at atomism in the early seventeenth century, it is important to remember that there were a variety of atomisms in play, not all of which fit in with a mechanist or corpuscular philosophy. For example, among a number of chymists and Aristotelian natural philosophers there was the view that the elements can be divided into minimal parts that would lose their status as elements if divided further. Because these smallest parts are distinguished from one another by having different essences, this *minima naturalia* view fails to satisfy Boyle's definition of the mechanical philosophy.[88] But more influential was the revival of the atomism of Epicurus and Lucretius. There were a number of people involved in this revival, including Sebastian Basso (ca. 1560–ca. 1621), Nicholas Hill (ca. 1570–ca. 1610), David van Goorle (1591–1612), among others. But the key figure was Pierre Gassendi. Gassendi's project was more than just natural philosophy; his aim was to rehabilitate

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later into Italy. On this, see Belgioioso, *Cultura a Napoli e cartesianesimo*; and Claudio Manzoni, *I cartesiani italiani (1660–1760)* (Udina: La Nuova Base, 1984).

[86] Boyle, *Works*, 3: 7.

[87] For general histories of atomism, see the still classic Kurd Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*, 2 vols. (Hamburg: L. Voss, 1890); Andrew Pyle, *Atomism and Its Critics from Democritus to Newton* (Bristol: Thoemmes Press, 1997); and Antonio Clericuzio, *Elements, Principles, and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (Dordrecht: Kluwer, 2000). Kargon's *Atomism in England*, gives a good history of atomism in seventeenth-century England. For an account of the variety of atomisms available in the early seventeenth century, see Lynn Sumida Joy, *Gassendi the Atomist* (Cambridge: Cambridge University Press, 1987), chap. 5. For an account of the revival of Epicureanism, see Howard Jones, *The Epicurean Tradition* (London: Routledge, 1989). For a more general account of corpuscularianism, see Norma Emerton, *The Scientific Reinterpretation of Form* (Ithaca, N.Y.: Cornell University Press, 1984), chaps. 3–4.

[88] On this doctrine, see Pierre Duhem, *Système du monde*, 10 vols. (Paris: Hermann, 1958), 7: 42–54; Emerton, *The Scientific Reinterpretation of Form*, chaps. 3–4; Newman, *Gehennical Fire*, pp. 24 ff.; Roger Ariew, "Descartes, Basso, and Toletus: Three Kinds of Corpuscularians," chap. 6 of his *Descartes and the Last Scholastics*. The position can be found in the writings of pseudo-Geber (on which see Newman, *Gehennical Fire*, pp. 94 ff.), Julius Caesar Scaliger, and Johannes Baptista Van Helmont, among many others.

Epicurean philosophy as a whole and present a cleansed version acceptable to a Christian audience.[89] For Gassendi, as for Epicurus, the world was made up of two principles: atoms and the void. Atoms were taken to be the smallest parts of matter, possessed of size, shape, weight, and nothing else. Although finite in size, and thus having physical parts, atoms were taken to be indivisible. In this way, they constituted the smallest level of analysis for any body. Furthermore, all the manifest properties of bodies were to be explained in terms of the size, shape, and motion of these atoms.[90]

Descartes presented an alternative mechanist foundation for the physical world. The commitment to a metaphysical grounding for physics was basic to Descartes' thought. One of the central elements of his metaphysics was his doctrine of the essence of body and its distinction from mind. Body, for Descartes, was a substance whose essence is extension and extension alone. By that, Descartes meant to exclude all properties in bodies except for size, shape, and motion; in this sense, one can say that bodies, or material substances, are, for Descartes, the objects of geometry made concrete.

Because bodies are the objects of geometry made real, they are infinitely divisible, and there is no smallest part of matter. Just as any finite line can be divided into smaller parts, so can any finite body be divided into smaller parts. (Although he differed from Descartes in many respects, Hobbes agreed with him in holding that matter is infinitely divisible and that there are no smallest particles.) Furthermore, insofar as they are extended and extended alone, Cartesian bodies have no innate tendency to descend or to do anything else. Gravity, for Descartes, was something that had to be explained in terms of the interaction between the heavy body and the particles in the ether that surround it; it could not be a basic, inherent property of body as it was for the Aristotelians and would become for the Newtonians.[91]

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[89] Epicurus faced the normal obstacles encountered by any pagan author attempting to enter the Christian intellectual world, and then some. In addition to the stigma of an ethics based on pleasure, Epicurus did his best to demystify the physical world by offering systematic naturalistic explanations of everything his contemporaries attributed to the gods. Epicurus furthermore argued that the gods themselves were made up of atoms and that they lived in places distant from the human realms and were uninterested in human affairs. On the Christianization of Epicurus's thought, see Margaret J. Osler, "Baptizing Epicurean Atomism: Pierre Gassendi on the Immortality of the Soul," in *Religion, Science, and Worldview*, ed. M. J. Osler and P. L. Farber (Cambridge: Cambridge University Press, 1985), pp. 163–83. It should be noted here that there are disagreements about whether Gassendi was a genuine believer or whether, in the end, he was a freethinker or even an atheist. The classic development of the view of Gassendi as a libertine is found in René Pintard, *Le libertinage érudit dans la première moitié du XVIIe siècle* (Paris: Boivin, 1943; Geneva: Slatkine Reprints, 1983). It is answered in Paul O. Kristeller, "The Myth of Renaissance Atheism and the French Tradition of Free Thought," *Journal of the History of Philosophy*," 6 (1968), 233–44.

[90] Gassendi's atomism is developed at some length in his posthumous *Syntagma philosophicum* (1658), in Gassendi, *Opera omnia*, 6 vols. (Lyon: Laurentius Anisson and Ioan. Baptista Devenet, 1658), 1: 256A ff. See also Bernard Rochot, *Les travaux de Gassendi sur Epicure et sur l'atomisme, 1619–1658* (Paris: J. Vrin, 1944).

[91] Descartes' physics is developed in the early *Le monde*, written in 1630–3 but first published in 1664 (Paris: Theodore Griard, 1664), and in the *Principia philosophiae*, pt. 2. For discussion of Descartes' physics and its metaphysical foundations, see Daniel Garber, *Descartes' Metaphysical Physics* (Chicago: University of Chicago Press, 1992). The relation between these issues in Descartes and in the schoolmen is discussed in Dennis Des Chene, *Physiologia: Natural Philosophy in Late*

Descartes and Gassendi represented the two main poles in seventeenth-century theories of matter.[92] There is every reason to believe that it was these two positions that Boyle had in mind when he chose to put aside the differences among different groups of corpuscularians. Although they may have differed on the question of whether there is an ultimate level of analysis of body, or whether every body, no matter how small, is divisible into smaller parts, they agreed in rejecting Aristotelian form and matter and in holding that the manifest properties of bodies are to be explained in terms of their size, shape, and motion. But, in addition to these positions, other alternatives were available.

Although the theory of matter was not central in the thought of Galileo, he did seem to subscribe to a kind of corpuscularianism. In a celebrated passage from the *Il Saggiatore* (The Assayer, 1623), he asserted: "To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, numbers, and slow or rapid movements. I think that if ears, tongues, and noses were removed, shapes and numbers and motions would remain, but not odors or tastes or sounds."[93]

However, it is important to note that Galileo's ultimate particles seem not to have been the small but finite corpuscles Boyle had in mind, but "infinitely many unquantifiable atoms," suggesting an infinitesimal conception, though this idea was not worked out in great detail.[94] Coordinate with the infinitesimal particles were infinitesimal voids. The consistency of bodies, Galileo argued, is caused by these tiny voids, interspersed in bodies, together with "the repugnance nature has against allowing a void to exist."[95] Galileo was, of course, aware of the Aristotelian arguments against the void from the infinite speed that a body in motion would seem to have when moved in a vacuum, but he thought that these arguments could be answered.[96]

One of the most interesting attempts to ground the conception of body and matter in connection with the mechanical philosophy is found in the work of Leibniz. From his earliest youth, Leibniz was captivated by the

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Aristotelian and Cartesian Thought (Ithaca, N.Y.: Cornell University Press, 1996). For an account of Cartesian physics in late seventeenth-century figures, see Paul Mouy, *Le développement de la physique cartésienne, 1646–1712* (Paris: J. Vrin, 1934). For Descartes' relation to atomism, see Sophie Roux, "Descartes Atomiste?" in *Atomismo e continuo nel XVII secolo*, ed. Egidio Festa and Romano Gatto (Naples: Vivarium, 2000), pp. 211–73.

[92] On the relations between Cartesianism and Gassendism later in the century, see Thomas M. Lennon, *The Battle of the Gods and Giants: The Legacies of Descartes and Gassendi, 1655–1715* (Princeton, N.J.: Princeton University Press, 1993).

[93] Galileo Galilei, *Il Saggiatore* (Rome: Giacomo Mascardi, 1623), in *Opere di Galileo Galilei*, 6: 350, translated in Drake, *Discoveries and Opinions of Galileo*, pp. 276–7. On Galileo's atomism, see William R. Shea, "Galileo's Atomic Hypothesis," *Ambix*, 17 (1970), 13–27; A. Mark Smith, "Galileo's Theory of Indivisibles: Revolution or Compromise," *Journal of the History of Ideas*, 27 (1976), 571–88; and Giancarlo Nonnoi, "Galileo Galilei: quale atomismo?" in *Atomismo e continuo nel XVII secolo*, ed. Egidio Festa and Romano Gatto, pp. 109–49.

[94] Galileo Galilei, *Discorsi e dimostrazioni*, in *Opere di Galileo Galilei*, 8: 71–2, translated in Drake, *Two New Sciences*, p. 33.

[95] Galileo, *Discorsi*, in *Opere di Galileo Galilei*, 8: 59, translated in Drake, *Two New Sciences*, p. 19.

[96] Galileo, *Discorsi*, in *Opere di Galileo Galilei*, 8: 105–6, translated in Drake, *Two New Sciences*, p. 65.

mechanical philosophy. But Leibniz's mechanism was not uncritical.[97] He came to see a number of problems with the mechanist conception of body in both the Cartesian and the atomist versions. Against the Cartesian conception of body, a substance whose essence is extension, he argued that extension is not itself the kind of thing that can exist alone. Rather, he argued, it is a relative notion that presupposes some quality that is extended. Just as one cannot have a father without a child, one cannot have mere extension without there being some quality that is extended.[98] Elsewhere, Leibniz argued that because Cartesian bodies are divisible, indeed infinitely divisible, they lack the kind of genuine unity required for something to be a substance.[99] Leibniz had a number of arguments against the atomists as well. If there are parts of matter that are indivisible, then they must be infinitely hard because all elasticity comes from smaller parts that can move with respect to one another. But if atoms were infinitely hard, then in collision, their speeds would change instantaneously, which violates Leibniz's principle that nature makes no leaps (the Principle of Continuity). He also argued that atoms are impossible because there is no reason why God should stop the divisibility of a piece of matter in one place rather than another, in violation of his celebrated Principle of Sufficient Reason.[100]

Despite his criticism of the prevailing mechanist accounts of body, Leibniz continued throughout his life to hold that there is a sense in which everything can be explained in terms of size, shape, and motion. But behind the extended bodies of the mechanical philosophy, he argued, there must be something more real, which he called individual substances; in that sense, his position constitutes a kind of substantial atomism. Sometimes these individuals were conceived of based on the model of Cartesian living things – corporeal substances with souls attached to bodies, making those bodies both active and genuinely unified. But more often, particularly in his later writings, Leibniz appealed to his monads. Modeled on Cartesian souls (that is, incorporeal substances), monads were genuinely active and genuine individuals. The bodies of everyday experience were just the confused appearance presented

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[97] See, for example, the intellectual biography Leibniz gives for his dealings with mechanism in his letter to Nicholas Remond, 10 January 1714, in Gottfried Wilhelm Leibniz, *Die philosophischen Schriften*, ed. C. I. Gerhardt, 7 vols. (Berlin: Weidmannsche Buchhandlung, 1875–90), 3: 606–7, translated in Leibniz, *Philosophical Papers and Letters*, ed. and trans. L. E. Loemker (Dordrecht: Reidel, 1969), pp. 654–5.

[98] This argument is found in an essay dated 1702, in Gottfried Wilhelm Leibniz, *Mathematische Schriften*, ed. C. I. Gerhardt, 7 vols. (Berlin and Halle: A. Asher et comp. and H. W. Schmidt, 1849–63), 6: 99–100, translated in Gottfried Wilhelm Leibniz, *Leibniz: Philosophical Essays*, ed. and trans. Roger Ariew and Daniel Garber (Indianapolis: Hackett, 1989), p. 251.

[99] See, for example, Leibniz's letter to Arnauld, 30 April 1686, in Leibniz, *Die philosophischen Schriften*, 2: 96, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 85. For an account of this and other arguments against the Cartesian conception of body, see Daniel Garber, "Leibniz and the Foundations of Physics: The Middle Years," in *The Natural Philosophy of Leibniz*, ed. K. Okruhlik and J. R. Brown (Dordrecht: Reidel, 1985), pp. 27–130.

[100] For an exposition of Leibniz's arguments against atomism, see Garber, "Leibniz: Physics and Philosophy," pp. 321–5.

by these substances; both the bodies and the laws that they obey are ultimately grounded in the world of genuine substances. What was truly real, for Leibniz, were these substances. Mechanism for Leibniz was grounded in something not purely material, either corporeal substances, which involve an immaterial soul, or monads, which are themselves immaterial substances.

Mechanist corpuscularianism often presented itself as a replacement for an Aristotelian conception of body. But this was not always the case. As mentioned earlier, there was an atomistic and corpuscularian tradition separate from the Epicurean and mechanist tradition and quite consistent with an Aristotelian conception of body, the *minima naturalia* view on which elements that by their nature were distinct were divisible into smallest parts that are also by their nature distinct. There were, in addition, many who tried to render the full-blown mechanical philosophy consistent with the Aristotelian philosophy that many mechanists thought it was meant to replace. Digby's widely read *Two Treatises* (1644), one of the early works written from a mechanist point of view, evinced great respect for the Aristotelian point of view and tried to show its consistency with Digby's own system. In the second half of the seventeenth century, as the mechanist program was gaining serious momentum, there were numerous books with titles like Jean-Baptiste Du Hamel's *De consensu veteris et novae philosophiae* (On the Agreement of the Old and New Philosophy, Paris, 1663), Jacques Du Roure's *La physique expliquée suivant le sentiment des ancients et nouveaux philosophes; & principalement Descartes* (Physics Explained in accordance with the Opinions of the Old and the New Philosophers, and Especially that of Descartes, Paris, 1653), Johannes de Raey's *Clavis philosophiae naturalis sive Introductio ad contemplationem naturae aristotelico-cartesiana* (The Key to Natural Philosophy; or, Introduction to the Aristotelio-Cartesian Contemplation of Nature, Leiden, 1654), René Le Bossu's *Parallèle des principes de la physique d'Aristote & celle de René Des Cartes* (The Parallels between the Principles of the Physics of Aristotle and René Descartes, Paris, 1674). Some of these works were simply comparisons of the old and the new. But, in numerous cases, authors tried to render consistent the matter and form of the schools with the size, shape, and motion of the moderns.[101] One of the young Leibniz's earliest surviving writings is a letter he wrote to his teacher, Jakob Thomasius (1622–1684), on 20/30 April 1669 (published by him a year later, virtually unchanged), naming a number of the most prominent adherents of this position and outlining his own way of reconciling Aristotelianism and the mechanical philosophy.[102] The ideas there were rather naive; he argued that Aristotelian

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[101] On this theme in seventeenth-century thought, see Christia Mercer, "The Vitality and Importance of Early Modern Aristotelianism," in *The Rise of Modern Philosophy*, ed. Tom Sorell (Oxford: Oxford University Press, 1993); and Mercer, *Leibniz's Metaphysics*.

[102] The letter can be found in Gottfried Wilhelm Leibniz, *Sämtliche Schriften und Briefe*, ed. Deutsche [before 1945, Preussische] Akademie der Wissenschaften (Berlin: Akademie Verlag, 1923–), 2.1: 15, translated in Loemker, ed. and trans., *Philosophical Papers and Letters*, pp. 93–103.

notions of matter, form, and change can be interpreted in mechanist terms, and that this is how Aristotle himself had understood them, a far cry from the much more sophisticated reconciliation one finds in Leibniz's mature writings. But, in a real sense, though the details change, the idea of grounding mechanistic physics on Aristotelian foundations remained with Leibniz for much of his life. Following Aristotelian practice, Leibniz often characterized his substances, both corporeal substances and monads or simple substances, in terms of matter and form, as I discuss in more detail. In this way, he could claim to have reconciled the new mechanical philosophy with the old scholastic Aristotelian philosophy. As Leibniz put it in the *Discours de métaphysique* (Discourse on Metaphysics, 1686), "the thoughts of the theologians and philosophers who are called scholastics are not entirely to be disdained."[103]

THE MECHANICAL PHILOSOPHY: SPACE, VOID, AND MOTION

Among the foundational issues, questions about space, place, and void were important to the Aristotelian philosophy of the schools and were widely discussed by some of the opponents to Aristotelianism discussed earlier. But the reintroduction of atomism by many mechanists brought with it a renewed interest in these questions and some new positions worth examining.

As discussed earlier, for Aristotle, empty space was impossible: All space was filled with body and could not be otherwise. Although he rejected Aristotle in many other respects, this was an issue on which Descartes agreed with him. For Descartes, as for Aristotle, space was not something over and above body. Because the nature of body is extension, and because every property (such as extension) requires something that instantiates that property, anything extended must be body. For Descartes, space was simply an abstract way of talking about extended bodies and their relations to one another, and the very idea of a vacuum was a conceptual impossibility. As a consequence, the world was full for Descartes, and there was no empty space, nor could there be. Because space was just a relation among bodies, place was defined in terms of the relations among bodies, as was motion for Descartes. Motion was a change of situation with respect to the bodies neighboring a given body. Although there was no fact of the matter whether a given body or

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[103] Gottfried Wilhelm Leibniz, *Discours de métaphysique* (written in 1686, unpublished during Leibniz's lifetime), para. 11, in Leibniz, *Sämtliche Schriften und Briefe* 6.4: 1529–88. They are not entirely to be disdained, but not entirely to be followed either. For the schoolmen, form was to explain the details of the behavior of bodies: why some fall and some rise; why some are hot and others are cold. This was not so for Leibniz. For Leibniz, all explanation in physics was in terms of size, shape, and motion. Matter and form enter in only to ground the reality of body by providing unity, and the general laws of motion by providing force and activity. In this way, Leibniz argued "that the belief in substantial forms has some basis, but that these forms do not change anything in the phenomena and must not be used to explain particular effects," *Discours de métaphysique*, para. 10.

its neighborhood is really moving when the two are separating from one another, there was, for Descartes, a fact of the matter about whether they are separating. In this way, Descartes hoped to make a real distinction between motion and rest, and reject the evident relativism that his position would seem to entail.[104]

The plenist position characterized the later Cartesian school and quite naturally went with the view that body is divisible to infinity. If the world is filled with no empty spaces, then bodies must be divisible indefinitely in order to prevent empty spaces from being formed as larger bodies move. Indeed, there are some circumstances in which bodies must actually be divided to infinity in order to guarantee that there are no vacua.[105] However, Descartes' position on the nature of motion was not generally followed. Christiaan Huygens (1629–1695), in his youth a follower of Descartes, built a physics where motion is understood to be relative to an arbitrarily chosen resting point.[106]

Those who revived atomism in the seventeenth century tended to favor views of space that held it to be independent of body and capable of existing empty, without body. As already mentioned, Galileo had rejected Aristotle's ban on the vacuum. For Galileo, the consistency of bodies was explained at least in part by the interspersal of tiny vacua throughout matter.[107] Like Epicurus, Gassendi argued for the existence of void space from the fact that, without a void, motion would be impossible, either at the macroscopic or the microscopic level. Although others had opposed the Aristotelian ban on the vacuum, Gassendi took the argument one step further, arguing that space is something that must be conceived outside of the Aristotelian categories of substance and accident.[108] But it was probably Gassendi's espousal of this position that would influence later thinkers such as Locke. As Locke wrote in his *Essay Concerning Human Understanding* (1690): "If it be demanded (as it usually is) whether this *Space* void of *Body* be *Substance* or *Accident*, I shall

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[104] This position is developed, for example, in Descartes' *Principia philosophiae*, 2.1–35. For a fuller discussion of the issues raised, see Garber, *Descartes' Metaphysical Physics*, chaps. 5–6.

[105] See Descartes, *Principia philosophiae*, 2.34–35. Descartes argues that in a specified region, for any body, however small, in that region, one can find a body smaller still. Because he wants to reserve the term "infinity" for God alone, Descartes calls this indefinite divisibility rather than infinite divisibility.

[106] The relativity of motion is central to Huygens's derivation of the laws of impact. By virtue of the doctrine of the relativity of motion, what appear as different physical situations in Descartes' derivation (*Principia philosophiae*, 2.40, 46–52) are identified with one another, allowing Huygens to present laws much more elegant than Descartes'. See Christiaan Huygens, *De motu corporum ex percussione* (1659), in Christiaan Huygens, *Oeuvres complètes*, ed. D. Bierans de Haan, J. Bosscha, D. J. Kortweg, and J. A. Vollgraff, 22 vols. (The Hague: Société Hollandaise des Sciences and Martinus Nijhoff, 1888–1950), 16: 30–168, trans. Richard J. Blackwell in "Christiaan Huygens's *The Motion of Colliding Bodies*," *Isis*, 68 (1977), 574–97. See also the discussion in Dijksterhuis, *The Mechanization of the World Picture*, pp. 373–80.

[107] See Galileo, *Discorsi e dimostrazioni*, in *Opere di Galileo Galilei*, 8: 71–2, translated in Drake, *Two New Sciences*, p. 33.

[108] Gassendi, *Opera*, 1: 182A. The position here is reminiscent of the one that Patrizi had taken some years earlier. On Patrizi's theory of space, see Grant, *Much Ado about Nothing*, pp. 204–5.

readily answer, I know not: nor shall be ashamed to own my Ignorance, till they that ask, shew me a clear distinct *Idea* of *Substance*."[109]

Locke also rejected with vigor the Cartesian identification of space with body.[110] As a result, he saw no problem with recognizing the possibility of empty space. He wrote: "Whatever Men shall think concerning the existence of a *Vacuum*, this is plain to me, That we have as clear an *Idea of Space distinct from Solidity*, as we have of Solidity distinct from Motion, or Motion from Space."[111]

Unlike Gassendi, Locke stopped short of saying that space definitely falls outside the categories of substance and accident, and he stopped short of asserting that space is a something that contains bodies, as opposed to a relation of sorts among bodies. But Locke was quite clear about rejecting the Cartesian identification of body and space and the consequent impossibility of the vacuum.

A similar position can be found in the writings of the Cambridge Platonist Henry More. Like Gassendi before him, More believed that space should be thought of as a container that contains all of the bodies in nature. But unlike Gassendi and Locke, More did not want to accommodate space by rejecting the categories of substance and accident. Although More agreed with Descartes that extension must be the property of something, he disagreed with Descartes in his claim that all extension must be body. Unlike Descartes, More argued that both body and soul are extended, the one extended and penetrable, the other extended and impenetrable. More argued that the appropriate substance to which to attribute the infinite extension of space is neither finite body nor finite spirit but God himself.[112]

Possibly related to More's view is one of Newton's, in his *Principia mathematica philosophiae naturalis* (Mathematical Principles of Natural Philosophy, 1687). There Newton presented an absolutist conception of space, which he contrasted with a relativist conception: "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."[113]

It is with respect to the immobile framework of this absolute space that absolute (as opposed to relative) motion is to be measured: Absolute motion

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[109] Locke, *Essay*, 2.13.17.

[110] Ibid., 2.13.11–17, 23–7.

[111] Ibid., 2.13.26.

[112] See Henry More, *An Antidote Against Atheism*, appendix, chap. 7, in his *A Collection of Several Philosophical Writings of Dr Henry More* . . . (London: Printed by James Flesher for W. Morden, 1662); and More, *Enchiridion metaphysicum* (London: Printed by James Flesher for W. Morden, 1671), chap. 8.

[113] Isaac Newton, *Philosophiae naturalis principia mathematica*, ed. Alexandre Koyré and I. Bernard Cohen, 2 vols. (Cambridge, Mass.: Harvard University Press, 1972), 1: 46, trans. Andrew Motte in Isaac Newton, *Mathematical Principles of Natural Philosophy*, revised by Florian Cajori, 2 vols. (Berkeley: University of California Press, 1934), 1: 6.

is simply motion with respect to this immobile framework.[114] Newton gave a number of criteria by which one can tell whether one is in motion, absolutely speaking, including his famous bucket experiment.[115] As More did, Newton seems to have identified space with God himself. In the General Scholium added to the second edition of the *Principia* (1713), Newton wrote that "He endures forever, and is everywhere present; and, by existing always and everywhere, he constitutes duration and space."[116] Elsewhere, Newton talked about space as God's sensorium: God "is more able by his Will to move the Bodies within his boundless uniform Sensorium, and thereby to form and reform the Parts of the Universe, than we are by our Will to move the Parts of our own Bodies."[117]

An interesting kind of intermediate position between the Cartesian and the Gassendist is found in Leibniz. Against the conception of space found, for example, in an Epicurean atomist such as Gassendi, Leibniz offered a conception of space as relative:

> I hold space to be something merely relative. . . . I hold it to be an order of coexistences, as time is an order of successions. For space denotes, in terms of possibility, an order of things which exist at the same time, considered as existing together. . . . Space is nothing else but . . . order or relation, and is nothing at all without bodies but the possibility of placing them.[118]

Although Leibniz agreed with Descartes in rejecting the idea of space as something that exists independently of the bodies that fill it, he disagreed with Descartes' identification of body and space. But although it is conceivable for Leibniz that there could be empty space, a wise God would not leave any space unfilled. In this way, Leibniz shared the Cartesian commitment to the idea that all space is full of body (along with the idea that all body is divisible

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[114] Although he agrees, in a sense, with Descartes in distinguishing motion and rest, his conception of the distinction is altogether different. See Newton's critique of Descartes' conception of motion in Isaac Newton, *De gravitatione* . . . , published in *Unpublished Scientific Papers of Isaac Newton*, ed. A. R. Hall and M. B. Hall (Cambridge: Cambridge University Press, 1962), pp. 89–156 (Latin original followed by English translation).

[115] In the bucket experiment, Newton imagines a bucket hung by a twisted cord and spun about so that the cord untwists. As the motion of the bucket communicates itself to the water, the surface of the water will become more and more concave as the water ascends the sides of the bucket. Newton writes: "The ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water, which is here directly contrary to the relative, becomes known, and may be measured by this endeavor." (Isaac Newton, *Principia mathematica* . . . , 1: 51, trans. Motte in Newton, *Mathematical Principles*, 1: 10.) The classic article on the question of Newton and absolute space and motion is Howard Stein, "Newtonian Space-Time," *Texas Quarterly*, 10 (1967), 174–200, reprinted in *The Annus Mirabilis of Sir Isaac Newton, 1666–1966*, ed. Robert Palter (Cambridge, Mass.: MIT Press, 1970).

[116] Newton, *Principia mathematica*, 2: 761, trans. Motte in Newton, *Mathematical Principles*, 2: 545.

[117] Question 31 in Isaac Newton, *Opticks; or, A Treatise of the Reflections, Refractions, Inflections & Colours of Light* (New York: Dover, 1952), p. 403; see also Question 28 in Newton, *Opticks*, p. 370.

[118] Leibniz to Clarke, 25 February 1716 (Leibniz's Third Paper), para. 4 in G. W. Leibniz and Samuel Clarke, *Correspondance Leibniz-Clarke*, ed. André Robinet (Paris: Presses Universitaires de France, 1957), p. 53; and G. W. Leibniz and Samuel Clarke, *The Leibniz-Clarke Correspondence*, ed. H. G. Alexander (Manchester: Manchester University Press, 1956), pp. 25–6.

to infinity) while sharing with the Gassendists the view that a vacuum is possible.[119] Interestingly enough, even though space was relative for Leibniz, motion was not. Leibniz held that in any situation in the physical world, one can designate any point as being immobile and the laws of physics will not be violated in that frame. But he also believed that at the metaphysical level of forces, there is a real distinction between motion and rest, and a fact of the matter about which bodies are really moving. Real motion, for Leibniz, involved real force: The bodies that are in motion are endowed with what he called living force (mass times velocity squared, mv^2).[120]

The question of absolute versus relative space gave rise to one of the most celebrated scientific disputes in the period, the debate between Leibniz and the Newtonians, as it unfolded in a series of letters between Leibniz and the English divine and friend of Newton's, Samuel Clarke (1675–1729).[121] There were many arguments on a number of issues, including the role of God in the universe and Leibniz's views on the relativity of space, time, and motion. A central consideration related to Leibniz's so-called Principle of Sufficient Reason, the claim that there must be a reason for everything. Leibniz pointed out that if there were absolute space, as Newton held, then one is forced to make distinctions without real differences. For example, if the world were to be moved five inches to the left, or if east and west were to be systematically reversed, the absolutist would have to hold that these worlds were really different. But if so, then there could be no reason for God to choose one of them over any of the others: Because the worlds are equally orderly and indistinguishable in all of their phenomena, God would violate the Principle of Sufficient Reason if he created any of them at all. This, for Leibniz, was a good reason for adopting a theory of space in which such worlds are not genuinely different. (This, of course, has the effect that, in the case at hand, because there is no difference between the starting place and the ending place, there is no motion either, properly speaking.) But Clarke was not satisfied. For Clarke, God was free to do what he liked: God's decision to create one possible universe over other possible and even indistinguishable universes is

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[119] For a more detailed account of Leibniz on space, see Garber, "Leibniz: Physics and Philosophy," pp. 301 ff.

[120] See, for example, *Discours de métaphysique*, para. 18; and Leibniz to Huygens 12/22 June 1694, in Leibniz, *Mathematische Schriften*, 2: 184, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 308. For a discussion of Leibnizian relativity, see Howard Stein, "Some Philosophical Prehistory of General Relativity," in *Foundations of Space-Time Theories*, ed. J. Earman, C. Glymour, and J. Stachel (Minnesota Studies in the Philosophy of Science, 8) (Minneapolis: University of Minnesota Press), pp. 3–49, esp. pp. 3–6, with notes and appendices; and Garber, "Leibniz: Physics and Philosophy," pp. 306 ff.

[121] For a close discussion of the exchange, see Ezio Vailati, *Leibniz and Clarke: A Study of Their Correspondence* (Oxford: Oxford University Press, 1997). Although it is clear that Newton played some role behind the scenes in Clarke's side of the correspondence, the exact extent is unclear. See Vailati, *Leibniz and Clarke*, pp. 4–5, and the references cited therein.

all the reason that is needed.[122] This exchange nicely illustrates the extent to which theological concerns were central to foundational debates about the nature of the physical world.

The issue of the nature of space and the possibility of a vacuum was one of the most important foundational issues in seventeenth-century physics. But even though it was foundational, aspects of the issue were thought to be amenable to empirical investigation, particularly the question of the real existence of the vacuum. In 1644, Evangelista Torricelli (1608–1647), a student of Galileo who worked in Florence, found that when one filled a tube that was closed on one side with mercury and then stood the tube up in a pool of mercury, if the tube was long enough, the mercury in the tube would fall and leave what appeared to be an empty space at the top.[123] This gave rise to considerable debate and discussion. The classic experiments were performed by Blaise Pascal (1623–1662) (see Dear, Chapter 4, this volume). There were two sets of experiments. The first were reported in Pascal's *Expériences nouvelles touchant le vide* (New Experiments on the Vacuum, 1647). There Pascal varied the experiments, using tubes of different widths, heights, and shapes. He used water and wine in addition to mercury in an attempt to show that the space at the top of the column was genuinely empty and filled neither with vapor from the liquid below nor with air that may have been in the liquid or seeped in through the pores in the tubes. He argued at that point that the column was held up by a limited "fear of the vacuum," a variant of the conception of the *horror vacui* common in Aristotelian science. Pascal's view changed in the *Récit de la grande expérience de l'équilibre des liqueurs* (Account of the Great Experiment on the Equilibrium of Fluids, 1648). There Pascal reported on the famous Puy de Dôme experiment, where his brother-in-law, Florin Périer, carried a barometer to the top of the Puy de Dôme, a high mountain in the Auvergne region of France, and compared the reading at the top with the reading of a similar apparatus at the bottom of the mountain. The fact that the column of mercury at the top was lower than the column of mercury at the bottom established, for Pascal, that it was the pressure of the air that kept the column at the level that it was; as one goes higher in the atmosphere, that air pressure decreases, causing the decrease in the length of the column. Pascal also concluded that nature does not abhor a vacuum and

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[122] See, for example, Leibniz to Clarke (Leibniz's Third Paper), 25 February 1716, para. 5, and Clarke's reply, Clarke to Leibniz, 15 May 1716 (Clarke's Third Reply), paras. 2, 5. Interestingly enough, in his correspondence with Clarke, Leibniz does not discuss Newton's bucket experiment for distinguishing between absolute and relative motion. However, he discusses it elsewhere, and rejects it. See Leibniz to Huygens 4/14 September 1694, in Leibniz, *Mathematische Schriften*, 2: 199, translated in *Leibniz: Philosophical Essays*, p. 308–9.

[123] The classic account of this discovery and its consequences remains C. de Waard, *L'expérience barométrique: ses antécédents et ses explications* (Thouars [Deux-Sèvres]: Imprimerie Nouvelle, 1936).

that all of the phenomena that had been attributed to the supposed horror of the vacuum are caused by the pressure of the ambient air.[124]

Pascal's experiments were widely discussed, though not universally accepted as establishing what Pascal claimed they did. Descartes, of course, for whom extension and body were the same, could not accept Pascal's conclusion that the vacuum exists. Although he was perfectly prepared to agree with Pascal that it was air pressure that supported the column of mercury, Descartes believed that the apparently empty space at the top of the column was really subtle matter that had entered through the pores of the glass.[125] This position was developed in more detail in a series of letters that Étienne Noël (1581–1659) sent Pascal in autumn 1647. (Noël was a Jesuit and may possibly have been Descartes' philosophy teacher at the Jesuit Academy of La Flèche.) Noël argued that the fact that light passes through the vacuum shows that the glass must have pores in order to allow the particles of light to pass through. And if light can pass through, so could small particles from the atmosphere.[126] This consideration was trenchant enough that even some supporters of the vacuum, such as Gassendi and his English follower Walter Charleton (1620–1707), agreed that it cast doubt on Pascal's conclusion.[127] In the end, the problem was solved (as many metaphysical problems seem to be) by simply setting the issue aside.[128] In his *New Experiments Physico-Mechanical, touching the Spring of the Air* (1660), where he first reported his famous air-pump experiments, Boyle wrote: "The Controversie about a *Vacuum* [seems to be] rather a Metaphysical, then a Physiological Question; which therefore we shall here no longer debate, finding it very difficult either to satisfie Naturalists with this Cartesian Notion of a Body, or to manifest wherein it is erroneous, and substute a better in its stead."[129]

For Boyle, the foundational question that goes beyond the ability of the experimenter to determine is a question that should be left aside.

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[124] The *Expériences nouvelles* can be found in Blaise Pascal, *Oeuvres complètes*, 7 vols. (Paris: Desclée de Brouwer, 1964–), 2: 493–513, translated in Blaise Pascal, *Provincial Letters, Pensées, Scientific Treatises*, trans. Thomas M'Crie (Great Books of the Western World), ed. Robert Maynard Hutchins, 54 vols. (Chicago: Encyclopaedia Britannica, 1952), 33: 359–81. The *Récit* can be found in Pascal, *Oeuvres complètes*, 2: 677–90, translated in Hutchins, ed., *Provincial Letters*, pp. 382–9. For accounts of the arguments, see, for example, P. Guenancia, *Du vide à Dieu: Essai sur la physique de Pascal* (Paris: Maspero, 1976); and Simone Mazauric, *Gassendi, Pascal et la querelle du vide* (Paris: Presses Universitaires de France, 1998).

[125] See Garber, *Descartes' Metaphysical Physics*, pp. 136–43.

[126] For Noël's correspondence with Pascal, see Pascal, *Oeuvres complètes*, 2: 513–40. For a survey of Noël's arguments, see Garber, *Descartes' Metaphysical Physics*, p. 143.

[127] See Gassendi, *Opera*, 1: 205A; and Walter Charleton, *Physiologia Epicuro-Gassendo-Charltoniana* (London: Printed by T. Newcomb for T. Heath, 1654), pp. 42–4.

[128] See Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, N.J.: Princeton University Press, 1985), pp. 45 ff., 119 ff.

[129] Boyle, *Works*, 1: 198.

THE MECHANICAL PHILOSOPHY: SPIRIT, FORCE, AND ACTIVITY

In the orthodox mechanical philosophy, everything was to be explained in terms of size, shape, motion, and the collision of corpuscles with one another, all governed by the laws of nature. This would seem to exclude any intrusion of mentality or incorporeal substance into the physical world. Among the main figures, only Hobbes espoused a straightforwardly materialistic philosophy and eliminated mind altogether.[130] Descartes introduced mind as a thinking thing, in contrast with body, whose essence is extension alone. As a consequence of these conceptions, mind and body were completely distinct from one another, and the one could exist without the other. Because this entailed a rejection of the Aristotelian conception of a soul, the principle of life, Descartes was committed to explaining the phenomena of life – digestion, reproduction, involuntary motions, and so forth – in purely mechanistic terms. The mind, an incorporeal and nonextended substance, explained thought and reason. But insofar as some of our activities involve rational processes of thought and choice and voluntary motion (I reach out and choose a book rather than a pack of playing cards), the mental world did on some occasions intrude into the physical world for Descartes.[131]

Henry More took Descartes' position further still. In his earlier years, More corresponded with Descartes and did much to advocate the study of his thought in England.[132] But even though he was a great advocate of the mechanical philosophy in many ways, More was convinced that much that the mechanists claimed to be able to explain mechanistically could not be so explained and required an appeal to what he called the "spirit of nature." This incorporeal principle was taken to explain "what remands down a stone toward the Center of the Earth . . . keeps the Waters from swilling out of the Moon, curbs the matter of the sun into roundness of figure," among many other things.[133] More characterized this spirit of nature as "a substance

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[130] There are some others whose views are associated with materialism. In his set of objections to Descartes' *Meditations*, Gassendi seems to adopt a materialist view against Descartes' famous dualism; see Descartes, *Oeuvres*, 7: 262–70, and his expansion of this in his *Disquisitio Metaphysica* (Amsterdam: Johannes Blaev, 1644), Gassendi, *Opera*, 3: 284B ff. However, in the *Syntagma*, he comes out quite clearly for the existence of incorporeal substance. See Gassendi, *Opera*, 2: 440A ff. Another character in the period often accused of materialism is Spinoza. Although his complex metaphysics does allow for the possibility of being interpreted in this way, insofar as the mind and body are, in a sense, identical, it can also be interpreted in other ways. See Benedict de Spinoza *Ethics*, in Spinoza, *Opera*, ed. Carl Gebhardt (Heidelberg: C. Winter, 1925), vol. 2, pp. 84–96, esp. Part 2, props. 1–13.

[131] For a development of this reading, see Daniel Garber, "Mind, Body, and the Laws of Nature in Descartes and Leibniz," in Garber, *Descartes Embodied* (Cambridge: Cambridge University Press, 2001), pp. 133–67.

[132] On More's role in the diffusion of Cartesianism, see Alan Gabbey, "Philosophia Cartesiana Triumphata: Henry More (1646–1671)."

[133] Henry More, *A Collection*, p. xv.

incorporeal, but without Sense and Animadversion, pervading the whole Matter of the Universe, and exercising a Plastical power therein . . . raising such Phaenomena in the world, by directing the parts of Matter and their Motion, as cannot be resolved into mere Mechanic powers."[134] More's conception of the world extended to other kinds of spirits as well. Along with his friend, the English natural philosopher Joseph Glanvill (1636–1680), More proselytized for the recognition of disembodied spirits, ghosts, and witches, arguing that they should be accepted by the very standards of belief espoused by the Royal Society.[135]

Another mechanist view that granted a large role to incorporeal substance was Leibniz's, where the ultimate entities, corporeal substances or monads, are understood to be immaterial substances or at least endowed with immaterial substances. But, Leibniz held, though the mechanist world is grounded in something that goes beyond matter and motion, everything in the physical world can be explained in terms of size, shape, and motion. For Leibniz, the appeal to incorporeal substance was needed not to explain individual events in the physical world but rather the very existence and nature of laws that govern those events. For example, Leibniz argued that if bodies were mere extension, as the Cartesians held, and contained nothing immaterial, then one body could not resist another in a collision, and a body A in motion colliding with a body B at rest would put body B into motion without diminishing the speed of body A in any way. In this situation, various conservation laws, such as the conservation of momentum and the conservation of mv^2, would be violated. In this way, Leibniz took great pains to distance himself from views such as More's, which involved the direct intervention of incorporeal substance in the material world.[136]

Closely related to the question of incorporeal substance in natural philosophy is the question of the activity of bodies and the real existence of force in the physical world. If the essence of body is extension alone, then it would appear that there is no room in body for any activity at all. For that reason, Descartes held that the motion of bodies in the world derives directly from

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[134] Henry More, *The Immortality of the Soul*, p. 193, in More, *A Collection*. A similar view is found in More's friend and colleague Ralph Cudworth. See Ralph Cudworth, *The True Intellectual System of the Universe* (London: Richard Royston, 1678). What corresponds in Cudworth's thought to More's Spirit of Nature is what he calls the plastic natures. Indeed, Cudworth goes so far as to argue that the purely materialistic (and atheistic) form in which atomism has come down to us is a perversion of the original, which before Democritus and Leucippus included incorporeal souls and an incorporeal deity in addition to atoms and the void (1.18, 41 ff.).

[135] See Daniel Garber, "Soul and Mind: Life and Thought in the Seventeenth Century," in Garber and Ayers, eds., *The Cambridge History of Seventeenth-Century Philosophy*, pp. 776 ff.

[136] See Part I of Gottfried Wilhelm Leibniz, *Specimen dynamicum* [1695], in Leibniz, *Mathematische Schriften*, 6: 242–3, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, pp. 125–6; and Gottfried Wilhelm von Leibniz, *De ipsa natura* [1698], para. 2, *Die philosophischen Schriften*, 4: 504–5, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 156.

God himself or from the finite minds to which he gave the ability to move bodies. As he wrote to Henry More:

> The translation that I call motion, is not something with less being than figure has, that is, it is a mode in body. But the moving force can be that of God, conserving as much translation in matter, as he placed in it in the first moment of creation, of that of some other created substance, such as our mind, or some other thing [an angel, for example] to which he gave the force for moving a body. . . . I consider "matter left free and having no other impluse" as plainly at rest. Moreover, it is impelled by God, conserving as much motion or translation in it as he placed there in the beginning.[137]

In this way, all motion (at least, all motion that does not derive from finite minds) derives directly from God. Despite this feature of his account of body, Descartes made free use of the notion of force in his physics. But as I discuss later in this chapter, given Descartes' grounding of the laws of nature (in which the notion of force plays its role) in God, it is fair to interpret his appeal to force as an indirect appeal to God. For example, it is because God maintains the motion that a body has that it appears to resist being stopped or being deflected from its rectilinear path.[138]

A general trend within Cartesian metaphysical physics after Descartes' death was the development and ultimate dominance of the doctrine of occasionalism. Although Descartes allowed that minds can be the causes of motion as well, many of Descartes' later followers, including Gérauld de Cordemoy (1626–1684), Louis de La Forge (1632–ca. 1666), Johann Clauberg (1622–1665), and Nicolas Malebranche (1638–1715), took the doctrine one step further and argued that God is the *only* genuinely efficacious cause in the world, eliminating both bodies and minds as real causes. For a variety of reasons, they argued that what appear to be instances of body–body causality (one body collides with another) or mind–body causality (the mind wills to raise the arm of the body to which it is attached) are really caused by God, carrying out the effects in accordance with laws that he has ordained for himself. According to one popular argument, for example, God's conservation of the world from moment to moment, which underlies Descartes' view of the laws of motion, makes any causal relations between finite creatures, minds or bodies, otiose. Another central argument, due to Malebranche, eliminates finite causes by arguing that only in the case of God do we find the necessary connection between cause and effect required for a genuine causal relation.[139]

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[137] Descartes, *Oeuvres*, 5: 403–4. The quotation in the passage is from More's letter to Descartes. There is a certain amount of controversy over whether the "some other thing" to which God gave the ability to move bodies is another body or another kind of spirit. On this, see Garber, *Descartes' Metaphysical Physics*, pp. 303–4.

[138] See Garber, *Descartes' Metaphysical Physics*, chap. 9.

[139] On occasionalism, see *Causation in Early Modern Philosophy*, ed. Steven Nadler (University Park: The Pennsylvania State University Press, 1993); and para. 10 of Nadler, "Doctrines of Explanation in Late Scholasticism and in the Mechanical Philosophy," in Garber and Ayers, eds., *The Cambridge History*

The atomist Gassendi would appear to be opposed to Descartes on this score. Gassendi did agree with Epicurus in holding that there is a sense in which bodies are genuinely active. Unlike Descartes, Gassendi held that God, in creating bodies, created them with genuine self-motion. Gassendi wrote in the *Syntagma philosophicum* (Treatise on Philosophy, 1658): "It seems that we must say . . . that the first moving cause in physical things is atoms; while they move through themselves and through the force which is continually received from the Author from the beginning, they give motion to all things. And therefore these atoms are the origin, principal, and cause of all motions which are in nature."[140]

But it is clear that for Gassendi, as for Descartes, the foundation of this activity was God: God was "the Author" who must continually sustain the force that he has given to bodies.

Leibniz seems to have taken Gassendi's views of the activity of bodies one step further by seeing force and activity not merely as properties of the basic stuff of the world but as, in a sense, definitive of the very notion of body. He wrote in an essay entitled "On the Correction of Metaphysics and the Concept of Substance" (1694):

> I say that this power of acting inheres in all substance, and that some action always arises from it, so that the corporeal substance itself does not, any more than spiritual substance, ever cease to act. This seems not to have been perceived clearly by those who have found the essence of bodies to be in extension, alone or together with the addition of impenetrability, and who seem to conceive of bodies as absolutely at rest.[141]

Given the close connection between activity and substantiality, it is not surprising that the notion of force entered into the very definition of substance for Leibniz. In his dynamics, Leibniz made two important distinctions with respect to force. First of all, there was the distinction between primitive and derivative forces, the distinction between the subject that is exerting the force (primitive) and the actual force exerted by the substance at a particular time (derivative). Derivative forces manifest themselves in motion and the resistance to motion at the level of observable bodies, governed by laws of motion that Leibniz proposes. Then there is the distinction between active and passive forces. Passive forces are exerted in reaction to other forces that act on the body; these forces include impenetrability and resistance. Active forces are exerted by the substance without being acted on; these include living force (the force associated with motion) and dead force (the kind of force found in a stretched rubber band). Leibniz claimed that primitive active force is, properly speaking, the substantial form of a substance, whereas primitive passive force constitutes the primary matter.[142]

For Leibniz, force and activity were essential parts of substance and thus very different from the inert corporeal substances of the Cartesian tradition. But, despite that, they do not act independently of God. Leibniz wrote in the essay "De ipsa natura" ("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 on 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.[143]

It is a subtle position that Leibniz was trying to outline here. Although God must continually conserve the world, for Leibniz as for many of his contemporaries, what he must conserve is a world of active substances that contain within themselves the grounds of their own activity.

THE MECHANICAL PHILOSOPHY: GOD AND FINAL CAUSES

It is evident from the preceding discussion that God had a large role to play in the mechanical philosophy. God was identified by some with the container space; he was appealed to in order to determine what is a rational choice and what is not in determining the structure of the world; and he was appealed to as the primary cause of motion in the world and as the ground of force and activity in the world. The mechanist's philosophy was infused with the divine spirit, in a sense. In addition to these uses of God in the mechanical philosophy, I would like to discuss two additional themes that relate to God and the mechanical philosophy: the controversies over final causes, and the use of God in the derivation of the laws of motion.

The world of Christian scholasticism was a world full of meaning: divine plans and divine designs. One of Descartes' most controversial positions was to put such considerations out of bounds for the physicist. He wrote: "When dealing with natural things we will, then, never derive any explanations from

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of Seventeenth-Century Philosophy. On the argument for occasionalism from divine sustenance, see Daniel Garber, "How God Causes Motion: Descartes, Divine Sustenance, and Occasionalism," in Garber, *Descartes Embodied*, pp. 189–202. For the argument from necessary connection, see Nicolas Malebranche, *De la recherche de la verité* (Paris: A. Pralard, 1674–5), 6.2.3.

[140] Gassendi, *Opera*, 1: 337A; cf. 1: 279B, 1: 280A.

[141] Leibniz, *Die philosophischen Schriften*, 4: 468–70, translated in Loemker, ed. and trans., *Philosophical Papers and Letters*, p. 433.

[142] Gottfried Wilhelm Leibniz, *Specimen dynamicum*, pt. 1, in *Mathematische Schriften*, 6: 236 ff., translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 119 ff.

[143] "De ipsa natura" [1698], sec. 8, *Die philosophischen Schriften*, 4: 508, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, pp. 159–60.

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."[144]

Benedict de Spinoza (1636–1677) took the argument one step further and denied not only that we could know final causes but that, strictly speaking, God had no intentions. The appendix to Part I of his posthumously published *Ethica* (1677) gave an elaborate argument for why it is wrong to think of God anthropomorphically, as if he acted with intentions.

Needless to say, this was not a position that was popular among most thinkers of the period. Boyle, for example, wrote an essay directly opposing Descartes, as well as those more radical than Descartes who eliminated final causes altogether, *A Disquisition about the Final Causes of Natural Things* (1688).[145] Although Boyle recommended that "a *Naturalist*, who would Deserve that Name, must not let the Search or Knowledge of *Final Causes* make him Neglect the Industrious Indagation of *Efficients*," he argued that "all Consideration of *Final Causes* is not to be Banish'd from Natural Philosophy: but *that* 'tis rather Allowable, and in some Cases Commendable, to Observe and Argue from the Manifest Uses of Things, that the Author of Nature Pre-ordain'd those ends and uses."[146] More generally, Boyle held that "by being addicted to *Experimental Philosophy*, a Man is rather Assisted than Indisposed, to be a *Good Christian*," as the subtitle to his *Christian Virtuoso* (1690–1) reads.[147]

Newton, too, embraced final causes. Writing in the celebrated General Scholium, added to the end of the second edition of the *Principia* in 1713, and referring to the order of the heavenly bodies, Newton noted that "It is not to be conceived that mere mechanical causes could give birth to so many regular motions. . . . This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being."[148] In this way, God is very much present to the world in ordering it and shaping it.

But the philosophically most sophisticated defense of final causes in the period was probably that of Leibniz. As a mechanist, Leibniz held that everything could be explained in terms of size, shape, and motion, in terms of efficient causes. But he also held that everything can be explained in terms

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[144] *Principia philosophiae*, 1.28. The material in brackets is from the 1647 French translation. Before Descartes, Bacon had also rejected final causes in physics. See Francis Bacon, *Novum Organum* (London: Joannes Billius, 1620), 1.48 and 2.2; and Bacon, *De dignitate et augmentis scientiarum* (London: I. Haviland, 1623), 3.4.

[145] Boyle, *Works*, 11: 79–151.

[146] Ibid., 11: 151.

[147] Ibid., 11: 281.

[148] Newton, *Principia mathematica* . . . , 2: 760, translated in Newton, *Mathematical Principles*, 2: 544; cf. Query 31 of Newton, *Opticks*, p. 402. There Newton dismisses Descartes' attempt to derive the current state of the world from an initial chaos without appeal to final causes as "unphilosophical."

of God's intentions. As he wrote in the *Specimen dynamicum* (An Example from the Dynamics, 1695):

> 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.[149]

Leibniz did not think that we should always appeal directly to final causes. He wrote in an essay from 1702: "[I]t 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."[150]

However, in some cases, particularly in optics, Leibniz thought that final causes could be very helpful in discovering things that are too difficult to discover using efficient causes, such as the sine law of refraction.[151]

This difference in attitude toward final causes is reflected in the very different ways in which Descartes and Leibniz derived the laws of motion from God. For Descartes, the laws of motion he proposed were justified by the claim that in sustaining the world from moment to moment, as he must do for it to remain in existence, God also preserves a certain quantity of motion in the world, and certain features of that motion, for example the tendency of a body in motion to remain in uniform rectilinear motion. In justification of his famous law of the conservation of quantity of motion (size times speed) in his *Principia philosophiae* (1644), Descartes wrote:

> For we understand that God's perfection involves not only his being immutable in himself, but also his operating in a manner that is always utterly constant and immutable. Now there are some changes whose occurrence is guaranteed either by our own plain experience or by divine revelation, and

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[149] Gottfried Wilhelm Leibniz, *Specimen dynamicum*, pt. I, in Leibniz, *Mathematische Schriften*, 6: 243, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, pp. 126–7.

[150] Gottfried Wilhelm Leibniz, "On Body and Force, May 1702," in Leibniz, *Die philosophischen Schriften*, 4: 397–8, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 254.

[151] See Leibniz, *Specimen dynamicum*, pt. I, in Leibniz, *Mathematische Schriften*, 6: 243, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, pp. 126–7; Gottfried Wilhelm Leibniz, "A Letter of Mr. Leibniz . . ." (July 1687), in Leibniz, *Die philosophischen Schriften*, 3: 51–2, translated in Loemker, ed. and trans., *Philosophical Papers and Letters*, p. 351. The sine law of refraction is discussed in Leibniz, *Discours de métaphysique*, para. 22. A specific example Leibniz refers to on a number of occasions is the "Unicum Opticae, Catoptricae, et Dioptricae Principium," *Acta eruditorum*, June 1682: 185–90, in Gottfried Wilhelm Leibniz, *Opera omnia*, ed. Louis Dutens (Geneva: Fratres de Tournes, 1768), 3: 145–51.

> either our perception or our faith shows us that these take place without any change in the creator; but apart from these we should not suppose that any other changes occur in God's works, in case this suggests some inconstancy in God. Thus, God imparted various motions to the parts of matter when he first created them, and he now preserves all this matter in the same way, and by the same process by which he originally created it; and it follows from what we have said that this fact alone makes it most reasonable to think that God likewise always preserves the same quantity of motion in matter.[152]

Descartes suggested similar derivations for the three subsidiary laws of motion that he proposes. It is important to note here that Descartes was *not* appealing to God's intentions or God's choice. The laws he proposed derive directly from God's nature: It is because of his immutability that God must act in the way in which he does, and because he acts that way, bodies obey Descartes' laws of motion.

Leibniz rejected Descartes' incorrect laws and replaced them with a set of conservation laws very much like the ones now used in classical mechanics. However, Leibniz also rejected the way in which Descartes derived the laws from God.

> [The laws of motion] 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. These beautiful laws are a marvelous proof of an intelligent and free being [God], against the system of absolute and brute necessity of Straton and Spinoza.[153]

In this way, the laws of nature, for Leibniz, derive from the free choice of a God who chooses the laws appropriate for this best of all possible worlds.

BEYOND THE MECHANICAL PHILOSOPHY: NEWTON

In many ways, Newton's world was the by then familiar mechanist/corpuscularian world of bodies governed by laws of motion. Although Newton eschewed any systematic statement of his theory of matter, it is reasonably clear that he rejected the Cartesian metaphysical physics and subscribed to a version of atomism in which he recognized both atoms and the

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[152] Descartes, *Principia philosophiae*, 2.36.

[153] Gottfried Wilhelm Leibniz, *Theodicy*, 1.345, in Leibniz, *Die philosophischen Schriften*, 6: 319; see also, for example, Leibniz, *Discours de métaphysique*, para. 21. Also see Gottfried Wilhelm Leibniz, *Principes de la nature et de la grâce* (written in 1714, but unpublished during Leibniz's lifetime), para. 11, in Leibniz, *Die philosophischen Schriften*, 6: 598–606. Strato of Lampsacus (d. 270 B.C.E.) was an ancient follower of Aristotle who had the reputation of denying providence. None of his works survive.

void.[154] Perhaps most surprising to his contemporaries, and most disturbing as well, was the extent to which Newton was willing to add active powers to bodies. Again, in the thirty-first Query to his *Opticks*, Newton wrote concerning the atoms that make up bodies:

> It seems to me farther that these Particles have not only a *Vis inertiae* . . . , but also that they are moved by certain active Principles, such as is that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies. These Principles I consider not as occult Qualities, supposed to result from the specifick Forms of Things, but general Laws of Nature, by which the things themselves are form'd.[155]

Newton's world was thus an active world composed of bodies with active principles, including but not limited to gravitation, that are central to the formation of the world we see around us.[156] In adding these active forces, perhaps as a result of his chymical studies,[157] Newton departed from the strict Boylean mechanism that was the hallmark of the previous generation; he thus admitted that not everything can be explained by matter and motion alone, and that there is action that does not work by direct collision but at a distance. It was this to which Leibniz, for example, objected. Leibniz saw Newton's obscure forces as a step backward from the clarity and intelligibility of the mechanical philosophy, a reversion back to the scholastic philosophy that the mechanical philosophy was supposed to replace, a departure from the clarity of action by impact, and a return to the obscurity of influences and occult qualities. With Newton (and his followers) in mind, Leibniz complained bitterly of the people of his day who "have such a lust for variety that, in the midst of an abundance of fruits, it seems they want to revert to acorns"; rejecting the clear truths of the mechanical philosophy, they show their "love for difficult nonsense."[158]

Leibniz did not live to see Newton's acorns grow into mighty oaks, or his nonsense transformed into the new common sense. Although Newton's conception of the world came to dominate European thought in the eighteenth

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[154] Kargon, *Atomism in England*, chap. 9.

[155] Newton, *Opticks*, p. 402.

[156] See the discussion by Daniel Garber, John Henry, Lynn Joy, and Alan Gabbey, "New Doctrines of Body and Its Powers, Place, and Space," in Garber and Ayers, eds., *The Cambridge History of Seventeenth-Century Philosophy*, pp. 553–623, at pp. 602 ff. It should be noted that there is considerable disagreement about the status of gravitation in Newton: whether he really thought that gravitation was a basic force of nature, or whether he thought that it could be explained by more basic, mechanical causes. However, at least some of his followers were willing to take the plunge and accept action at a distance. See, for example, Roger Cotes's preface to the second edition of Newton's *Principia* (1713), in *Principia mathematica*, 1: 19–35, esp. 27–8, translated in *Mathematical Principles*, 1: xx–xxxiii, esp. xxvii. On the status of gravitation, see Ernan McMullin, *Newton on Matter and Activity* (Notre Dame, Ind.: Notre Dame University Press, 1978), chap. 3.

[157] On Newton and chymistry, see Westfall, "Newton and the Hermetic Tradition," and Dobbs, *The Foundations of Newton's Alchemy*, chap. 6.

[158] Gottfried Wilhelm Leibniz, *Antibarbarus physicus*, in Leibniz, *Die philosophischen Schriften*, 7: 337, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 31.

century and replaced the stricter mechanical philosophy of the seventeenth century, the particular foundations that Newton himself supplied were not always adopted along with the physics. There were attempts to ground Newton's physics in different metaphysics, including the idealistic metaphysics of Bishop Berkeley (1685–1753), the monadological metaphysics of Leibniz's German followers, the atoms of force of Rudjer Bošcović (1711–1787), David Hume's (1711–1776) psychologistic foundations of causality, and the magisterial system of Immanuel Kant (1724–1804). But in contrast with the sixteenth and seventeenth centuries, when the foundational enterprise was closely linked with the scientific enterprise itself, later developments in technical physics seemed largely independent of the different attempts to provide it with appropriate foundations.

CONCLUSION: BEYOND FOUNDATIONS

The ultimate fate of the Newtonian system in the eighteenth century illustrates a fundamental shift in scientific thought with regard to foundational questions. In the beginning of the period examined in this chapter, the idea of foundations is quite central to the idea of the study of nature. By the end of the seventeenth century, this idea had not been altogether abandoned by any means but had changed its status in fundamental ways. By this time, I think it is fair to say that the enterprise of physics and the enterprise of grounding physics have largely separated from one another and become rather separate disciplines.

This separation had been prepared for some time before. Already in the works of Boyle, questions about the vacuum and the infinite divisibility of matter, questions that go beyond the ability of experiment to resolve, had become metaphysical in a pejorative sense and had been placed beyond the domain of the natural philosopher. By the end of the seventeenth century, even Leibniz, one of the heirs of the program for a metaphysical physics, had come to separate the domain of physics proper from its metaphysical foundations and argued that the physicist need not concern himself with that domain. Leibniz's grounding of his mechanist world in a conception of substance was very different from that of Descartes, involving the positing of incorporeal substances in nature and the way in which God enters into the metaphysical grounding of his conception of the natural world. But, Leibniz argued, metaphysics and theology should not be the concern of the physicist, properly speaking. Writing in his *Discourse on Metaphysics*, he noted:

> Just as a geometer does not need to burden his mind with the famous labyrinth of the composition of the continuum, there is no need for any moral philosopher and even less need for a jurist or statesman to trouble himself with the great difficulties involved in reconciling free will and God's providence, since the geometer can achieve all his demonstrations and the statesman can complete all his deliberations without entering into these discussions, discussions that remain necessary and important in philosophy and theology. In the same way, a physicist can explain some experiments, at times using previous simpler experiments and at times using geometric and mechanical demonstrations, without needing general considerations from another sphere. And if he uses God's concourse, or else a soul, animating force [*archée*], or something else of this nature, he is raving just as much as the person who, in the course of an important practical deliberation, enters into a lofty discussion concerning the nature of destiny and the nature of our freedom.[159]

In this disciplinary separation of foundations from the science that it grounds are born both philosophy and science as we have come to know them.

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[159] Leibniz, *Discours de métaphysique*, para. 10, in Leibniz, *Sämtliche Schriften und Briefe* 6.4: 1543–44, translated in Ariew and Garber, eds. and trans., *Leibniz: Philosophical Essays*, p. 43.