WHEN SCIENCE & CHRISTIANITY MEET

Edited by

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To Susan E. Abrams, loyal friend, editor par excellence, and indefatigable supporter of scholarship on the history of science.

CONTENTS

short, examined in seventeenth-century terms, the outcome of the Galileo affair was a product not of dogmatism or intolerance beyond the norm, but of a combination of more or less standard (for the seventeenth century) bureaucratic procedure, plausible (if ultimately flawed) political judgment, and a familiar array of human foibles and failings.

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3

Christianity and the Mechanistic Universe

William B. Ashworth Jr.

In the second half of the seventeenth century, a new philosophy of nature came into prominence. Although it was presented in several distinct forms by the likes of René Descartes, Pierre Gassendi, and Robert Boyle, in all forms it treated matter as lifeless and inert, without any properties of its own. It also suggested that all natural phenomena could be explained by the mechanical interactions of matter in motion. This "mechanical philosophy," as it came to be called, was in strong contrast to the picture presented by traditional philosophies, such as Aristotelianism, and by other, newer, philosophies of nature that had been constructed in the late Renaissance, such as natural magic and Paracelsianism.[1]

The acceptance of the mechanical philosophy played a major role in the events that we collectively call "the Scientific Revolution." What concerns us here is the impact of this new philosophy on religion, specifically the Christian religion, as well as the impact of Christian thought on the mechanical philosophy. It is not immediately obvious that there should have been any interaction at all, since matter theory and theology would seem to be widely separate domains of inquiry. And yet, as we will see, the proponents of a mechanical philosophy were driven by religious concerns, the debate between different forms of the mechanical philosophy was waged on religious grounds, and the success of the mechanical philosophy was hailed as a Christian triumph. Religion and the mechanical philosophy were, in fact, inextricably linked throughout the seventeenth century.[2]

One might proceed to develop this story in any of several ways, but I think it would be helpful to have a mechanical philosophy in view before we go any further. Once we understand the basic features of one mechanical philosophy, it will be easier to appreciate the nonmechanical philosophies that preceded it, as well as the rival versions of a mechanical philosophy that would eventually be proposed. Since René Descartes was chronologically the first to publish a mechanical philosophy, we will begin with his version.

The Mechanical Philosophy of René Descartes

Descartes (1596–1650) (fig. 3.1) came of age in France at a time of considerable concern over the conflicts between traditional forms of knowledge (including religion) and the new discoveries of the late Renaissance. Where previously there had been one well-established Church, one known world, and one picture of the cosmos, there were now (ca. 1600) a variety of Christian churches, a recently discovered New World, and several new cosmologies. In France this resulted in what has been called the "skeptical crisis," with writers such as Michel Montaigne (1533–92) despairing that perhaps we can never know truth with certainty.[3] Descartes reacted to this skeptical crisis by deciding to doubt everything that he had been taught. He found that through methodical doubt he could arrive at certain "clear and distinct" ideas that could not be doubted no matter how hard he tried, and on these foundations he erected a new philosophy. He presented the outlines of this new philosophy in his *Discourse on Method* (1637), and he worked out most of its details in the *Principles of Philosophy* (1644).[4]

When it came to determining the "clear and distinct" attributes of matter, Descartes found that he could easily doubt most of the features that his predecessors had assigned to matter. An object before us may feel warm, smell sweet, or appear red, but Descartes was certain that these qualities could not be found in the matter itself—the stuff of which this object is composed. Here is how Descartes made the argument, in his *Second Meditation:*

> Let us now . . . consider the objects that are commonly thought to be the most distinctly known, namely, the bodies that we touch and see. . . . Take, for example, this piece of beeswax; . . . it has not yet lost the taste of the honey it contained; it still retains something of the odor of the flowers from which it was gathered; its color, shape, and size are apparent [to sight]; it is hard, cold, easily handled, and sounds when struck with the finger. Thus all that contributes to make a body as distinctly known as possible is found in the one before us. But while I am speaking, the wax is placed near a fire: it loses the remains of its taste, its odor evaporates, its color changes, its shape is destroyed, its size increases, it is liquified, it becomes hot, it can hardly be handled, and it emits no sound when struck. Does the same beeswax still remain after this change? It must be acknowledged that it does: nobody would deny it or

Figure 3.1. Portrait of René Descartes (1596–1650), from Charles Perrault, *Les hommes illustres qui ont paru en France pendant ce siecle: avec leurs portraits au naturel* (Paris: Chez Antoine Dezallier, 1696–1700), 1:59. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

> judge otherwise. What, then, was it in the wax that I knew so distinctly? Nothing, apparently, that came to me through my senses; since all the features that came under taste, smell, sight, touch, and hearing are now altered—and yet the same wax remains.[5]

It followed for Descartes that those characteristics perceived by the senses (he called them "secondary qualities") were illusions of the senses. They represented appearance, not reality. One by one, Descartes threw out all of the traditional attributes of matter, until he came to the one feature he could not doubt. Matter, to be matter, has to occupy space. In Descartes's terms, it has to have extension. So Descartes defined matter as extension and extension as matter. It follows that matter has no other properties than the occupancy of space.

The implications of this radical redefinition of matter were profound. If matter has no properties but extension, then all it can do is move about and collide and move some more. It cannot attract, or seek, or sympathize with other matter. It can only be pushed about, and therefore everything that happens in the universe must be reducible to matter in motion and matter colliding with other matter. Descartes went further. Since extension is identical with matter, there can be no extension without matter and, therefore, no empty space. The universe must be filled with matter, a plenum. Since we do not see a matter-filled universe, some forms of matter must be imperceptible. Descartes uses the expression "third matter" to refer to matter that we perceive with our senses, and the term "second matter" to refer to the imperceptible matter that fills all space between the chunks of third matter. The tiny spaces between particles of second matter must also be filled, which requires the postulation of a "first matter" (fig. 3.2). All of this matter is in continual motion.

Descartes found that the picture that resulted from this new view of matter has a great deal of explanatory power. For example, in a universe filled with matter, particles must move in closed circles, or whirlpools. If particles were to move in straight lines, then the motion of one particle would necessitate the displacement of an infinite number of successive particles. Descartes called whirlpools "vortexes" (or "vortices"). We can imagine then that our solar system is a vortex of swirling second matter, carrying with it the large chunks of third matter, the planets. The ultrafine first matter is forced to the center, where it forms the Sun (fig. 3.3). The light and heat of the Sun are conveyed to us by pressure transmitted through the intervening second matter. We have, as a result, a mechanical model of the solar system that is quite satisfying, since it explains why the planets move and why they all move in the same plane and the same direction, and it predicts that the central body will be different from the planets that move around it.[6]

There is more to Descartes's mechanical philosophy, but further details require the introduction of God and Christianity into the picture, and so at this point it would seem desirable to sketch out the philosophy of nature that Descartes was reacting against. When he went to the Jesuit college at La Flèche, he was taught a rather different theory of matter, deriving ultimately from the writings of Aristotle, as interpreted by the Scholastic theologian Thomas Aquinas (d. 1274).

Aristotle's Theory of Substance

Two thousand years earlier, Aristotle (384–322 B.C.) had defined "matter" quite differently. His term for things that exist of themselves—what we think of today as physical objects, such as rocks or tables or pieces of wood—was "substances." But a substance must be understood, Aristotle argued, as a composite of "form" and "matter." By "form," Aristotle meant the total collection of qualities or properties that make a thing what it is. However, properties must be the

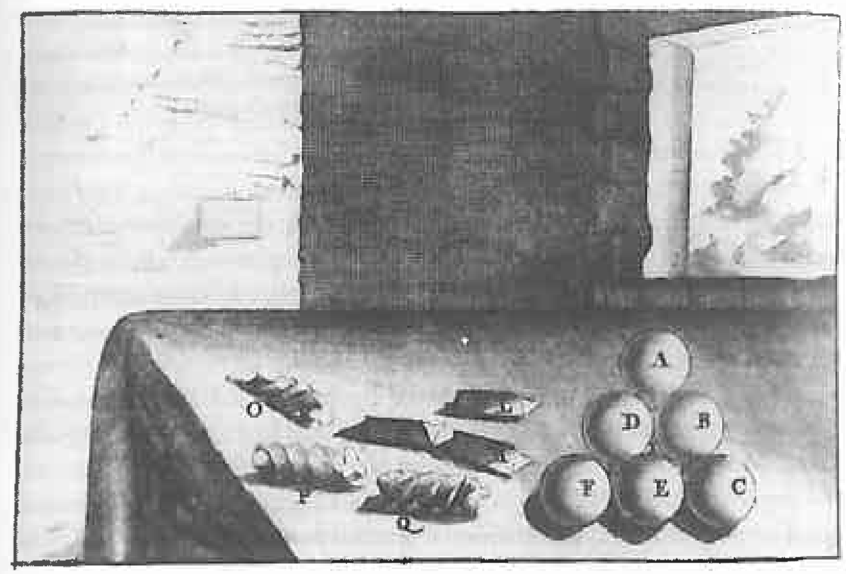

Figure 3.2. A figurative representation of Descartes's three kinds of matter. The screw-shaped and prism-shaped particles represent "first matter," which fills all the spaces between "second matter," represented by the stacked spheres. "Third matter," the ordinary matter we see and feel, is represented by the table and the wall. From Wolferd Senguerd, *Philosophia naturalis, quatuor partibus* . . . 2d ed. (Leiden: Apud Danielem á Gaesbeeck, 1685), 192. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

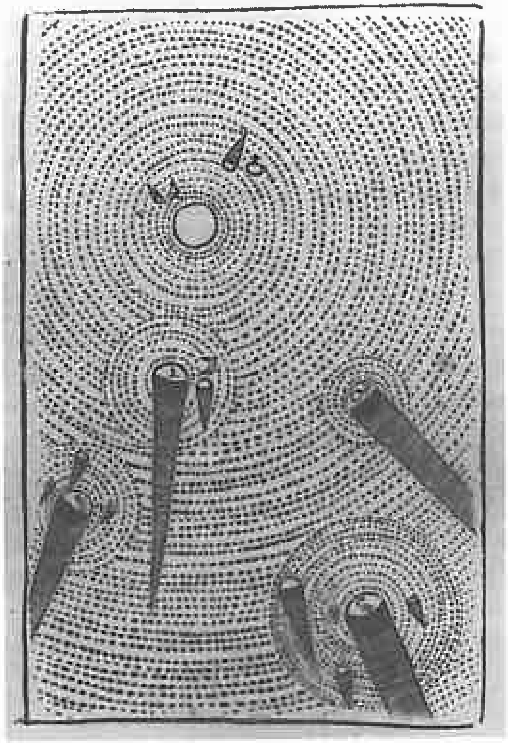

Figure 3.3. A diagram of the solar system, by a follower of Descartes's vortex theory. The Sun is the center of the principal vortex, which carries the planets around, but each planet also has its own vortex, which moves its moons about and is also responsible for gravity. From Petrus Hoffwenius, *Synopsis physica disputationibus aliquot academicis comprehensa*, 2d ed. (Stockholm, 1698), 84. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

attributes *of* something, and that something, for Aristotle, was "matter." Matter is the "stuff" of a substance; when matter has been "informed," a substance results. Aristotle also has an expression for matter that has not been informed: he calls it "first matter." But in reality, matter and form exist only as a composite; we can never encounter either one by itself.[7]

Aristotle's scheme can be nicely illustrated by his theory of the four elements: earth, water, air, and fire. Like all other really existing things, these four elements are substances. Earth results when first matter is endowed with the qualities cold and dry. Water is the cold and wet element, air is hot and wet, and fire is hot and dry. These elements may be combined in various proportions to produce all of the substances that make up the world.[8]

According to Aristotle, forms can be either "substantial" or "accidental." Qualities or properties that make a thing what it is comprise its "substantial form"; a table, for example, must have a top and legs, and be hard and have weight. These traits make up its substantial form. A table might also be brown and smooth and smell of vinegar; these properties are not essential, and they are referred to as "accidental qualities."

When it came to explaining how the world operates, or how one object interacts with another, Aristotle had recourse to what he called the "natures" of objects. Nature is a rather complicated concept in Aristotle, since it involves both form and matter, but in essence, it is simply that which determines an object's behavior. A rock, for example, is heavy "by nature," so if you drop it, it will fall, seeking its natural place at the center of the universe. A tree by nature grows up, and because that is its nature, it does not have to defy gravity to do so. A planetary sphere is inclined by its nature to move in a circle, which explains why the heavens are dominated by circular motion. For Aristotle, a great deal of the motion in the world is natural and does not require explanation by forces. Where motion is unnatural or violent, Aristotle does suggest that a motive force is necessary. But because such motion is not natural, it will cease, and the object will come to rest, as soon as the force is removed. It follows that Aristotle did not embrace a principle of inertia, or the idea that motion is conserved. But then, in the world of everyday experience, objects do slow down and stop when you leave them alone.

The picture that Aristotle painted of the material world was an eminently satisfying one, well in accord with common everyday experience, and so it is not surprising that it was fully integrated into Scholastic philosophy in the thirteenth century, after it was translated into Latin. Initially, there was some significant tension between Aristotelianism and Christianity (see chapter 1 of this volume), especially with respect to Aristotle's thoughts on the eternity of the universe and the mortality of the soul. But his matter theory was accommodated more readily, since it had considerable explanatory power, and it had no serious competition. Once it was assimilated, scholars discovered that certain aspects of this matter theory were quite useful in interpreting certain Christian doctrines. The Christian soul, for example, could be explained as the "form" of the body, the immaterial feature that gives the body its defining essence. There was even an unexpected fringe benefit in the ability of Aristotle's theory of form and matter to make sense of the sacrament of the Eucharist. Church doctrine had established that when the host is consecrated, the bread of the wafer is miraculously converted to the body of Christ, although it still appears to be bread. In Aristotelian terms, one could now say that the substantial form of the bread was changed, while the accidental form of bread remained. So Aristotle's theory of substance provided a perfectly acceptable explanation of both the observed phenomenon and the miracle.

Because of its conformity with sense experience and its compatibility with Christian doctrine, Aristotle's theory of form and matter survived intact well into the seventeenth century, where the mechanical philosophy would confront it head-on. But even before then, philosophies of nature that rivaled Aristotle's had arisen, and we need to be aware of several of these.

Renaissance Natural Magic

In the late Renaissance there arose a whole host of alternative natural philosophies, which have been variously labeled as "Hermetic" or "naturalist" or "magical"; we will use the terms "magical" and "natural magic" to refer to these philosophies. Natural magic tended to accept Aristotelian matter theory as a starting point, but it unleashed on the Aristotelian worldview a battery of new forces and influences. At the heart of natural magic was the belief that any object in the universe can potentially affect any other object, provided that a sympathy is established between them. There were many examples of natural sympathies that could be pointed to; the seven planets in the heavens seem to correspond to the seven metals in the earth, suggesting that there is a sympathy between Mars and iron and between the Sun and gold. Analogy further suggests that there might be sympathies between Mars and a warrior, the Sun and a yellow flower, or the Sun and the human heart. Sympathies ruled the magical universe, and these sympathies, it was argued, could be manipulated by the natural philosopher. If you were under the influence of the melancholy planet, Saturn, and wanted to change your mood, you might wish to establish a sympathy between yourself and a beneficent planet, say the Sun. You could do so by wearing a yellow robe, singing songs in praise of the Sun, playing your lute in a solar mode, and drinking wine from a golden goblet, and so replace your spirit of melancholy with a happier frame of mind.[9]

One of the attractions of natural magic was the fact that there are many phenomena in the world that seem sympathetic in nature. If you have a shop full of lutes and you pluck a string on one, strings on others will magically begin to vibrate, and if you check, you find that all the resonating strings have the same pitch. They seem to be vibrating in sympathy. Magnetism appears to be another example of a sympathetic force. A magnet attracts only iron, it works at a distance, and it is undeterred by a barrier. It is difficult to explain how a magnet works if you do not invoke a sympathy of some sort.

One other interesting feature of natural magic is that it placed great emphasis on experiment and observation. It did so because nature seems to be such a maze of forces that reason alone could never sort it all out. Aristotelians tended to think about how nature works; natural magicians tinkered with nature instead. One of the great personal guides to the Renaissance world of phenomena was the *Magia naturalis* (1589)[10] of Giovanni Battista della Porta (1535–1615). Della Porta described endless experiments and tricks that could be performed with magnets, mirrors, ovens, bleaches, dyes, and explosives, and he regularly used sympathies and correspondences to explain why a magnet attracts iron, how lenses magnify, why strings resonate, and how medicines cure. His book presented a view of nature in which matter can move matter over great distances by means of attraction and repulsion. Very rarely were these forces thought of as mechanical in their action.

Renaissance natural magic ran into some opposition from religious authorities, especially the Catholic church. The problem was that a magical worldview threatens the idea of miracles. In a world where anything can happen naturally, little room is left for the supernatural. In the aftermath of the Protestant Reformation, miracles were one of the defining features of Catholicism, and the church did not take kindly to attempts to treat miracles as natural phenomena, because, in effect, it undermined the whole idea of divine intervention. The church also took a dim view of those who moved beyond planetary influences and attempted to manipulate angels and demons. Such "black magic" was attacked vigorously, and most natural magicians such as della Porta carefully maintained their distance from such practices.[11]

Natural magic maintained its vigor well into the lifetime of Descartes. In 1617 Robert Fludd (1574–1637) published a very popular book, *On the Greater and Lesser Worlds*, in which he argued that, since the human body is a microcosm of the universe (the macrocosm), we can map all the correspondences that connect the two worlds, and Fludd did so with a number of attractive engravings. A common feature of all the various images of microcosm and macrocosm are the dotted lines and harmonic ties that, in effect, are the lines of force that make the universe work. And it is worth stressing again that there are no mechanical forces in this world of cosmic sympathies.[12]

The Religious Implications of Cartesian Mechanism

If we now return to Descartes and view him in the light of both Aristotelian and Renaissance natural philosophy, we see the almost shocking novelty of his mechanical philosophy. In making extension the sole attribute of matter, Descartes denied the real existence of all other qualities. Accidental forms are only names for the products of our perception; they do not really exist in nature. Substances do not have "natures" or natural tendencies of any kind. There are no such forces as sympathies or correspondences. The only allowable forces are mechanical forces. Magnetism must be explained mechanically without recourse to sympathies, and Descartes described a possible mechanical model for the magnet. Alleged sympathies that cannot be explained mechanically are denied existence in the Cartesian universe.

Matter is one ingredient of Descartes's universe. Mind is the other—the only thing besides matter that God created. Mind is immaterial and, according to Descartes, endowed only with the property of thought. The existence of mind was Descartes's initial clear and distinct idea: *Cogito, ergo sum* (I think, therefore I [a thinking being] must exist). Everything in Descartes's universe is either mind or matter, and nothing is both. Indeed, mind and matter intermingle only in humans, for mind is identical with the human soul. Since plants and animals have no soul and thus no mind, it follows that they consist solely of matter, and they should be regarded simply as mechanical automatons—nothing more than intricate pieces of machinery.

What were the religious implications of Descartes's mechanical philosophy? Since the prevailing philosophy of his time was Scholasticism, which was thoroughly imbued with Aristotle's theory of form and matter, we might expect there to have been considerable conflict. Descartes, however, saw no problems for religion in his mechanical philosophy. After all, his second clear and distinct idea was the existence of God, and it was God's perfect wisdom that guaranteed Descartes's entire reasoning process. Descartes maintained that his universe of matter was created by God, that God gave this matter a certain amount of motion at the Creation, and that he has conserved that motion ever since. Nevertheless, Descartes did envision a God who worked through natural causes and who allowed the universe to build itself by laws that he had established at the Creation. Descartes's God was like a watchmaker, who created a world that basically ran itself. This would prove to be a controversial notion, as we shall see.[13]

The proposal of other, non-Cartesian, mechanical philosophies complicated matters. Descartes had constructed his natural philosophy from the ground up, with little attention to earlier authorities. However, there were other mechanical philosophies around, one of which had been in existence long before Aristotle was born. This was the atomic philosophy of Leucippus (fl. 435 B.C.) and Democritus (fl. 410 B.C.).

Ancient Mechanical Philosophies

Ancient Greek atomism postulated that all matter is composed of atoms, which are by very definition indivisible bits of matter. Atoms are infinite in number, and they differ only in size and shape. All atoms are made of the same stuff, and they have no qualities except possibly their immutability. The differences we perceive in objects are solely the result of differences in the arrangement of their constituent atoms. Leucippus and Democritus also postulated the existence of void space. All atoms are in motion in the void, and they have been in motion forever. Atoms continually collide and react and form arrangements that we perceive, and then break up and move on. In fact, we, the perceivers, are ourselves only a fortuitous assemblage of atoms, like all other objects.[14]

The Democritean scheme allowed for material atoms and the void and nothing else. In particular, there are no really existing immaterial things. The soul, then, must be made of atoms. The atoms of the soul could be especially elegant ones, fine and proper, but they are still material. Similarly, gods were welcome in the atomic universe, but they too are composed of atoms, and are therefore no more immune from the laws of nature than any other object.

The Democritean world is truly a mechanical world. There are no Aristotelian forms, no souls, no purposes. Everything is the result of matter in motion, undergoing collisions, and assembling in chance configurations. To Aristotle and many others, such a world—without order, without purpose, and without a divine being—could not possibly be the world in which we live.

However, atomism as a natural philosophy did not immediately wither and die. In the generation after Aristotle, Epicurus (341–270 B.C.) attempted to revive it. Epicurus was primarily an ethical philosopher, who sought a prescription for human happiness, and since, in his opinion, most anxieties are the result of irrational fears, he searched for a worldview that would lay such fears to rest. He found it in atomism, with its repudiation of the supernatural, its banning of divine intervention, and its determined commitment to exclusively natural causation.[15]

But Epicurean atomism differed from that of Leucippus and Democritus. Epicurus gave the atoms an additional property, namely weight, which is what causes them to move. In effect, all atoms are continually falling through an infinite universe, as a sort of cosmic rain. Since it is difficult to see how or why a rain of falling atoms could interact (since all are falling in parallel lines at the same speed), Epicurus introduced a purely arbitrary element into the universe, which he called the "swerve." The swerve causes an atom to deviate from its straight-line descent, leading to a chain reaction of collisions and ultimately the world in which we live. Epicurus presumably introduced the swerve to forestall complete determinism and to keep a modicum of free will alive in the world. However, the swerve also keeps the Epicurean universe from being completely mechanical, since the swerve is arbitrary, an event without a cause.

As an ethical philosopher, Epicurus inspired a considerable following. As a natural philosopher, however, he was less influential. He did attract the attention of Lucretius (ca. 99–55 B.C.) whose great poem *On the Nature of Things* is an espousal of Epicurean atomism. But the apparently atheistic character of Epicureanism, with its eternal universe, infinite atoms, and material souls, attracted few adherents in the early Christian centuries or in any centuries thereafter, until the surprise of the seventeenth.

Gassendi's Revival of Ancient Atomism

Pierre Gassendi (1592–1655) (fig. 3.4) was another original thinker who emerged from the skeptical crisis of the sixteenth century with a fistful of new programs. He was a youthful participant in the campaign of Marin Mersenne (1588–1648) against both Renaissance Aristotelianism and natural magic. He was an early believer in the value of an experimental method. He turned the newly invented telescope on the heavens, tracking planets and attempting to map the Moon. In the wake of Galileo's new physics, he performed experiments on falling bodies; he constructed ingenious barometric tubes in the aftermath of Torricelli's invention of the barometer. With respect to matter theory, Gassendi was, like Descartes, dissatisfied with Aristotelian explanations and angry at magical ones. But Gas-

Figure 3.4. Portrait of Pierre Gassendi (1592–1655), from Charles Perrault, *Les hommes illustres qui ont paru en France pendant ce siecle: avec leurs portraits au naturel* (Paris: Chez Antoine Dezallier, 1696–1700), 1:63. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

sendi was much more of a humanist than Descartes, for he believed in the wisdom of ancient philosophy, and he would reject Aristotle only in favor of a wiser ancient authority. He found that wisdom, against all odds, in the writings of Epicurus.[16]

To someone opposed to Aristotelian forms and qualities and distressed about sympathies and correspondences, the attractions of atomism are obvious. Atomism dispenses with all qualities and all causes that are not reducible to matter in motion. The problem with atomism, at least in its Epicurean clothing, is that it hardly seems compatible with Christianity. Epicurus taught that the world is infinite in time and space and was uncreated. He thought that the soul is material and mortal. Epicurus believed in more than one god, and the deities of his world are material like everything else and subject to the laws of nature. There is no purpose in the Epicurean world, and certainly no divine providence. The Christian, however, believes that one immaterial God created the world out of nothing at one specific time; that there are no other worlds than this one; that purpose is everywhere; that there is an immaterial human soul capable of salvation; and that divine providence rules.

For a Catholic priest like Gassendi, seeking an alternative to Aristotle, Epicurus would thus seem an unlikely choice, but Epicurus is where Gassendi bet his intellectual life savings. In a series of works written between 1647 and his death in 1655, and culminating in his *Philosophical System*, published posthumously in 1658, Gassendi re-presented Epicurean philosophy, with modifications that would make it acceptable to Christian thinkers.[17] In his version, Gassendi agreed that the world was made of indivisible passive atoms, which differed only in size and shape. These atoms moved and congregated in a void, and all large-scale effects are reducible to differences in the sizes, shapes, and configuration of atoms. However, these atoms are not infinite in number, nor are they eternal. Rather, God created the atoms, and he made only a finite number of them. God also infused motion into the atoms when he created them, providing them with just the right amount to fulfill his providential intentions. So Gassendi was able to dispense with the arbitrary swerve.

Gassendi also reasserted the immateriality of the soul. And he maintained that the soul was capable of influencing matter, thus allowing for the reinstitution of free will.

Gassendi versus Descartes

Thus two distinctly different mechanical philosophies emerged in the 1640s. They shared the desire to remove substantial forms, sympathies, and correspondences as explanatory devices, preferring instead to reduce all explanation to the motion of tiny, insensible, and totally passive particles. However, Descartes and Gassendi disagreed as to whether these particles were ultimately indivisible (Gassendi) or divisible (Descartes), and as to whether the universe was filled with matter (Descartes) or consisted of matter moving through void space (Gassendi). They also disagreed about the role of God in shaping and maintaining a mechanical universe.

Descartes viewed God as a supremely wise Creator, who created the universe from nothing and then let it run, like a machine, by itself. According to Descartes, God created matter, put it in motion, conserved that motion, and then withdrew and allowed the universe to unfold on its own accord; God was not needed to supervise every step of the process. Descartes did maintain that God preserves the universe at every moment, implying that the conservation of matter and motion would cease instantly if God did not act to maintain it. Nevertheless, Descartes's God appears much more like a wise designer than a constant shepherd; Descartes thus left himself open to the charge that God, having created the world, seemed no longer necessary.

Gassendi had a somewhat different conception of the deity. He believed that God had complete freedom to create any sort of world he wished, and that poor mankind, with its feeble intellectual powers, was in no way equipped to deduce anything about the resulting product. We may construct laws of nature, but they are our laws, not God's, and he is not constrained by them. Since we cannot figure out the nature of the universe by rational means, we have no choice but to stick to observable phenomena and perform experiments; and to explain these phenomena, we should devise the simplest, most straightforward hypothesis available. For Gassendi, that hypothesis was atomism. We can imagine atoms, and how they move, and how they interact, and we explain virtually every natural phenomenon by these atomic interactions. But that is as far as we can go; we can never know the underlying mechanisms with certainty.[18]

Hobbes and the Early Signs of Danger

Although both Gassendi and Descartes emphasized the role of God in the creation and maintenance of the universe, while excluding the soul from mechanical explanations, it was apparent, from the example of Democritus himself, that the mechanical philosophy might be theologically dangerous in the wrong hands. The danger became manifest in the work of Thomas Hobbes (1588–1679). Hobbes became an atomist in the 1640s, perhaps as a result of encounters with Gassendi, and by the time of the publication of his great *Leviathan* (1651), he had become a thoroughgoing materialist. That is, Hobbes maintained that the universe consists of matter in motion and nothing else. There are no forms, no spirits, no nonmaterial entities in Hobbes's world. There are no forces other than impact. Souls exist, but they are material, rather than spiritual. Even God himself is a material rather than a spiritual being. Hobbes denied the possibility of free will. He ruled out all absolutes; good, evil, justice, and injustice became relative terms, which acquired meaning only through human definition. While Hobbes was not an atheist, he held religiously dangerous views, including doubts about the authenticity of Scripture. As a result, the "monster of Malmsbury" came to represent, in the eyes of many, the religious peril presented by a mechanical philosophy.[19]

There were several ways of dealing with the threat of Hobbes while still retaining a mechanical philosophy. One could argue that mechanism alone is not sufficient to explain the world—that spiritual entities of divine origin are necessary. This would be the route taken by the Cambridge Platonists. Or one could argue that a functioning mechanical universe would be possible only if God designed it and that indeed mechanism demonstrates the wisdom and providence of God. This would be the path taken by Robert Boyle.

More, Cudworth, and the Spirit of Nature

The Cambridge Platonists, as their name suggests, were a small group of scholars who taught at Cambridge University in the 1640s and 1650s and who preferred the writings of Plato (427–347 B.C.), and of Neoplatonists such as Plotinus (A.D. 205–269/70), to the more traditional Aristotle. They sought to establish a rational Christian religion, arguing that all of the tenets of Christianity could be demonstrated by reason from Platonic principles. Among the group who went by the name of Cambridge Platonists, two in particular wrestled with the religious implications of the mechanical philosophy: Henry More and Ralph Cudworth.

More (1614–87) was a fellow at Christ's College, Cambridge, who discovered Descartes in the mid-1640s.[20] He was attracted immediately by Descartes's version of the mechanical philosophy. He admired the way it explained, so rationally, the mundane properties of matter, and More was largely responsible for introducing Cartesian natural philosophy to England, where it would flourish. But by 1650 More had grown critical of Cartesianism because he thought that mechanism alone could not explain many phenomena, such as gravity or magnetism. There was no way, More argued, that the interaction of colliding particles in a vortex could produce a downward tendency in an object, as Descartes maintained. There must be something else in the universe, something nonmaterial and nonmechanical that provides direction in such instances. More proposed that such a substance exists, which he called the "Spirit of Nature." This spirit was incorporeal and devoid of will or reason; it pervaded the whole universe and directed matter to produce those effects that could not be produced by purely mechanical means. The Spirit of Nature was, in effect, God's agent in the world; it was the means by which God gave life to a mechanical universe without having to watch over it every minute.

This idea, that a mechanical universe cannot function successfully without the presence of immaterial spirits, would prove popular in the second half of the seventeenth century, especially in England. It seemed to provide a way of refuting the materialism of Hobbes by arguing that matter in motion is *not* sufficient to explain the world.[21] More's fellow Platonist Ralph Cudworth (1617–1688) wrote *The True Intellectual System of the Universe* (1678), a massive treatise in which he argued that the mechanical philosophy, properly understood, was not a threat to religion, but a new support, because it demonstrated the necessity of spiritual agents (fig. 3.5).[22] Cudworth called his principal agent "plastic nature," and he pointed to one of the advantages of such a nonintelligent agency—that it could explain mistakes. Accounting for imperfections in the world was always difficult when they were ascribed directly to God; they were much easier to accept if they were regarded as the result of a blind immaterial force like plastic nature.

Boyle and Corpuscularianism

Robert Boyle (1627–91) (fig. 3.6) was just as appalled as the Cambridge Platonists by Hobbes's materialism and by the apparent threat to revealed religion of an uncompromising mechanical philosophy. But Boyle found a different way of dealing with the problem.

Boyle is best remembered as a proponent of an experimental approach to studying nature. In his well-known experiments with air pumps, he discovered the elasticity of the air (and Boyle's law) and demonstrated the role of air in combustion and respiration.[23] He has also been hailed as one of the founders of modern chemistry and an opponent of alchemy (although recent research has revealed that Boyle had quite an interest in higher, as opposed to vulgar, alchemy). At heart, however, Boyle was a lay theologian who pursued scientific inquiry because it demonstrated to him the existence, wisdom, and attributes of God. We will say more about this after we examine the road that led Boyle to the mechanical philosophy.

Like many of his generation, Boyle was bothered by the forms and qualities that were used by Scholastic Aristotelian philosophers to explain ordinary phenomena. To say that a substance is red because it has the form of redness, or that

Figure 3.5. The Cambridge Platonists had difficulty reconciling Epicurean atomism with Christianity. Ralph Cudworth put Epicurus among the "atheists" on the frontispiece to his *The True Intellectual System of the Universe* (London: Printed for Richard Royston, 1678). (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

an object falls because its substantial form includes the quality of gravity, seemed to Boyle to be less an explanation than an act of labeling. We don't really understand why acids burn or roses smell if we simply attribute their effects to forms that exist only as names.

In a treatise that he wrote specifically on this subject, *On the Origin of Forms and*

Qualities, Boyle proposed that a theory of matter, to be useful, should have explanatory power. It should help us understand how an effect can occur. It should be plausible and intelligible, and it should be as simple as possible. Notice that Boyle does not say that it should be true. To discover the true constitution of matter is probably well beyond the poor powers of human reason. But we can certainly do better than substantial forms.[24]

The philosophy of nature that Boyle settled on was the mechanical philosophy, but it was not the version proposed by either Gassendi or Descartes. Boyle did accept as a working premise that all things can be reduced to matter in motion, which is the heart of a mechanical philosophy. But he did not commit himself to unbreakable atoms, or to Descartes's infinitely divisible matter having the sole property of extension; he thought that in practice there were smallest units, which he called corpuscles, but in theory there was no reason why these could not be further and indefinitely divided. Boyle accepted the void; indeed, he was

Figure 3.6. Portrait of Robert Boyle (1627–91), from *The works of the Honourable Robert Boyle*, ed. Thomas Birch (London: Printed for J. and F. Rivington, 1772), vol. 1, frontispiece. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

one of those who demonstrated its existence. Boyle called his version of the mechanical philosophy "corpuscularianism."[25]

Boyle embraced corpuscularianism for several reasons. One reason was that it made sense of experience in a plausible manner. It is hard to understand how an acid works if you attribute its action to the form of acidity. But if you imagine an acid as a tiny sharp corpuscle that can move between two other corpuscles and force them apart, then you have a mechanism that the human mind can understand. Heat can be visualized as the collective motion of many corpuscles. Cohesion might be the result of particles that lock or stick together. The resulting world picture was clear and easy to comprehend. For Boyle, that met the test of an acceptable natural philosophy.

Boyle, however, had another, and perhaps a prior, reason for defending a mechanical philosophy. If the orderly, organized, purposeful world in which we live is nothing more than an immense system of particles in motion, then it can hardly be the result of chance. It must have been designed by a God of extraordinary wisdom and providence. As Boyle put it:

> It is intelligible to me, that God should at the beginning impress determinate motions upon the parts of matter, and guide them, as he thought requisite, for the primordial constitution of things; and that ever since he should, by his ordinary and general concourse, maintain those powers which he gave the parts of matter, to transmit their motion thus and thus to one another.[26]

Boyle rejected the notion that God had to work through a Spirit of Nature or through any other kind of intermediary:

> It more sets off the wisdom of God in the fabric of the universe, that he can make so vast a machine perform all those many things, which he designed it should, by the mere contrivance of brute matter managed by certain laws of local motion and upheld by his ordinary and general concourse, than if he employed from time to time an intelligent overseer, such as nature is fancied to be, to regulate, assist, and control the motions of the parts.[27]

Finally, it was Boyle who gave us the concept of the world machine. He compared the world to a clock, whose parts were so exquisitely made that it would run perfectly long after the Maker had put it in motion. Boyle conceived this metaphor of the clocklike universe in order to support his belief that a wise God would design a world that does not need constant adjustment. But it was soon put to use as a proof of the existence of God. After all, if you found a watch on the ground, you would naturally infer the existence of a watchmaker. Then certainly a universe that runs like the most exquisite clock mandates the existence of a Creator God. Moreover, a mechanical world is not only proof of the existence of God, but testimony to his wisdom and providence. It is the best argument going against atheism.[28]

Boyle's view that the study of nature provides evidence of God's existence and attributes would lead to a movement known as natural theology. Its aim was to show that the "Book of Nature" could supplement the "Book of Scripture" in leading us to God and demonstrating his wisdom and foresight. Boyle himself left a sum of money upon his death in 1691 to fund an annual series of lectures, known as the Boyle Lectures, whose purpose was to use the Book of Nature to prove and teach the tenets of Christianity. These lectures would be one of the principal vehicles for natural theology up through Darwin's time in the nineteenth century.[29]

Although Boyle continually argued that the design of nature evidenced the wisdom of God, it is important to note, as a final point, that Boyle's God (like Gassendi's) had total freedom to create any kind of universe he wished. He was wise and providential, but he was not constrained by anything, certainly not laws of nature. There may be a general order of nature, but Boyle had no problem with God's tinkering with that order naturally, or even intervening miraculously. Indeed, Boyle believed that there are many things about the world that we will never understand because they are beyond the limits of human reason.[30]

The other interesting feature of Boyle's mechanical philosophy, a feature that also arose from his theological concerns, is its ecumenical character. Boyle tried to formulate a natural philosophy that all Christians could adopt. He carefully avoided taking a stand on the existence of atoms, so that his corpuscularian theory could be adopted by both Cartesians and Gassendian atomists. He never insisted on the truth of any of his mechanical explanations, offering them instead as possible and plausible. He even tried to appeal to Aristotelians and Paracelsians, by pointing out that the four elements, or the three principles, could themselves be reduced to corpuscles. His goal was simply to formulate a view of nature that allowed us to understand and marvel at the wonder of the created order, so that we might better appreciate the glory of the Creator. He thought that a mechanical philosophy fulfilled that aim.

Newton and the Limitations of Mechanism

Mechanical philosophers before Newton disagreed a great deal, about whether matter was atomic or infinitely divisible and about the existence or nonexistence

of empty space. But they generally agreed on one principle: that bodies interact only by contact. Any other means of passing motion from body to body was deemed magical, and thus suspect. Action at a distance was nothing but a sympathy and was not to be entertained by any serious mechanical philosopher.

Isaac Newton (1642–1727) (fig. 3.7) challenged this basic assumption by redirecting the mechanical philosophy to a new focus: that of forces.[31] He proposed to explain the operations of nature by various forces that could be mathematically described, and he did so with great precision in his *Principia mathematica* (1687). The mathematical treatment of forces does not require any inquiry into their origin, and Newton generally avoided discussing causes. But it was apparent to Newton, and to his readers, that the forces that produce such effects as fermentation, animal motion, and gravitation could not be ascribed to mechanical impacts. This would be a severe problem for more orthodox mechanical philosophers.

Newton converted to the mechanical philosophy around 1664, during his undergraduate years at Cambridge. His formal education was Scholastic, and

Figure 3.7. Portrait of Isaac Newton (1642–1727), from his *Philosophiae naturalis principia mathematica*, 3d ed. (London: Apud Guil. and Joh. Innys, 1726), frontispiece. (Courtesy of the Linda Hall Library of Science, Engineering and Technology)

thus Aristotelian, but he introduced himself to the works of Gassendi, Walter Charleton (1620–1707),[32] Hobbes, Boyle, More, and, most importantly, Descartes, and he was soon won over by the explanatory power of matter in motion. Although initially enamored of Descartes, Newton found problems in Descartes's theories of light and gravity, and he came to prefer some sort of atomic model. He would remain an atomist the rest of his life. At the same time Newton seems to have discovered, probably through More, the dangers of mechanism, with its tendency to exclude spirit from nature. This drove him even further from Descartes.[33]

Initially Newton also accepted the principle that all change of motion is a result of impact, and as he forged his way to a theory of universal gravitation in the 1670s and early 1680s, he assumed that some sort of aether was responsible for the tendency of bodies to "gravitate"—to move toward one another. He had to finally reject this notion when he discovered that the planets do not act as if they were moving through any kind of aether, because observational evidence made it clear that they are not impeded in any way. The Sun attracts the earth, but it does not do so through a material medium. Gravity is not a mechanical force.

Universal gravitation was, of course, one of the great discoveries of the century, but it caused great problems because of its nonmechanical nature. Christiaan Huygens (1629–95), for example, simply could not believe that nature would employ a force that acted at a distance. Huygens had himself discovered several of the physical laws that led to the discovery of universal gravitation, such as the law of centrifugal force, and he could have taken the additional step to the law of gravitation, but apparently his adherence to the mechanical philosophy of Descartes made that impossible.[34] What was it about Newton, equally devoted to a mechanical philosophy, that allowed him to break with one of its fundamental tenets? It has been suggested that Newton's theology might have made it possible for him to accept what others found unacceptable.

Newton's religion was a curious affair. He was fiercely Christian, but he avoided taking holy orders (a customary requirement for a Cambridge fellow) because he could not subscribe to one of the major tenets of the Anglican Church, namely, the doctrine of the Trinity. Newton was an Arian, believing that Christ was the son of God, but not himself divine. He kept his Arianism a secret during his lifetime, but his private writings leave no doubt about his views. Newton was also intensely interested in biblical prophecy, and he believed that God had revealed all of future history in the Books of Daniel and Revelation, if one knew how to read them.[35] Whether Newton's Arianism or his interest in prophecy directly affected his natural philosophy is hard to say. Most historians do not see much connection.

But one aspect of his theology might have influenced his mechanical philosophy. Newton shared Gassendi's and Boyle's view that God had total freedom in his creative work, that he was unconstrained by any laws of nature. Mere humans, with our feeble powers of reasoning, can never know the fine points of the world that God created. He could have done whatever he wished, by whatever means he wished. So it is possible that when Newton's inquiries suggested that bodies attract each other by a force whose mechanism we cannot imagine, he was more inclined to accept it.[36] Newton's God could directly cause the gravitation of bodies simply by willing it, and who are we to deny it as inconceivable? After all, most divine attributes are inconceivable.

Whether or not Newton's religious views helped shape his version of the mechanical philosophy, there is no doubt that Newton used the mechanical philosophy to advance his religious views. Newton was adamantly opposed to the watchmaker God of Descartes, who created a universe that ran by itself. Newton's God, the God of prophecy, was always active in the world, and Newton took it upon himself to show that a mechanical universe could not maintain itself without God's continual supervision. In a famous query that he appended to the Latin edition (1706) of his book on optics, Newton points out that material bodies are passive; they do not move of their own accord. Therefore all of the motions and changes that characterize our world must have some source other than the natures of those bodies. Newton called these sources "active principles" and held them responsible for gravity, magnetism, fermentation, and other apparently nonmechanical forces.

Active principles might seem out of place in a mechanical philosophy; to call something an "active principle" seems little better than to label it a "substantial form." Newton was aware of this, and he speculated during his career about how active principles might operate. At times he inclined to the idea that they were the result of God's direct intervention; at other times he pursued a material explanation, such as an aether, or an immaterial one, such as a spirit. In the end, he could not resolve the problem. But he did believe that active principles exist and that they are God's means of ordering and bringing activity to the world and of exercising divine providence. Newton believed that it was utterly impossible that our universe could have arisen by blind chance through the mere action of passive laws of nature.[37]

Newton went a step further; he argued that without divine intervention, the universe would run down. He calculated that the planetary orbits were inherently unstable, so that the solar system would eventually break down without some adjustment. Newton proposed that comets were the means by which God fine-tuned the cosmos and brought everything back into proper alignment. Gottfried Leibniz (1646–1716), the German philosopher, was appalled at the suggestion that God was such an inferior craftsman that he had to keep tinkering with his Creation to keep it running properly.[38] But Newton was unabashed. Leibniz was in the Cartesian tradition and saw God as the all-wise Creator who could make a universe that would run forever. Newton rejected that vision, because it made God essentially unnecessary once the universe was created, and this meant that it could lead to atheism. Newton preferred a God who was always with us, always reminding us of his presence.

For Newton, then, a mechanical philosophy without God was unimaginable. A universe of blindly moving atoms could never fortuitously produce an orderly world such as ours, and even if it could, that world would rapidly grind to a halt. A God of wisdom was necessary to create it, and a God of providence was necessary to maintain it. The fact that God chose, in this instance, to make a universe that ran like a clock, on mechanical principles, was interesting, because it was a system of nature that humans could understand. However, our understanding is unimportant unless it leads us to continual awareness of the universe as a product of divine handiwork.

Conclusion

Newton, Boyle, Descartes, and Gassendi all subscribed to some version of the mechanical philosophy. They also believed in an all-wise, all-powerful God who had once created and still preserved this universe of matter in motion. None of these natural philosophers saw any conflict between the two beliefs; in fact, one might go so far as to say that they found these two creeds, Christianity and the mechanical philosophy, inseparable and equally necessary.

It is important to appreciate how remarkable and unexpected this development was. The mechanical philosophy had been greeted with outrage by the early church fathers, who regarded mechanism as a path to atheism. It survived the Middle Ages only as an object of abuse. It aroused little interest even in the eclectic Renaissance. And yet in the seventeenth century, the mechanical philosophy was revived, refurbished, and embraced by Christian philosophers, who not only came to see a mechanical universe as intrinsically Christian, but who eventually put mechanism forward as a bulwark against atheism.

4

Matter, Force, and the Christian Worldview in the Enlightenment

Thomas H. Broman

In the minds of most people, historians and nonhistorians alike, the eighteenth-century Enlightenment occupies a pivotal position in the evolving relationship between science and religion. For it was during the Enlightenment that the cultural landscape of Europe was first reshaped in a way that enabled "science" and "religion" to emerge as separate and hostile camps in a long polemical struggle. That the Enlightenment did play this part in defining the relationship between science and Christianity was asserted by no less an authority than Peter Gay, whose two-volume masterpiece, *The Enlightenment: An Interpretation* (1966, 1969), represents the twentieth century's greatest synthesis on the subject. In the eighteenth century, Gay wrote,

> the evidence for a growing disenchantment, a growing component of critical rationalism in the minds of educated Christians, is overwhelming. For religious men sensitive or learned enough to participate in the currents of the century this was a time of trouble. The dangers of atheism and materialism, the threat of secularism, had been cried up for centuries. . . . But in the age of Enlightenment realities seemed to bear out the predictions of the most pessimistic Christians.[1]

The cause of this skepticism and disenchantment toward traditional religious belief, as Gay makes clear elsewhere in his study, was what *of Science*, trans. Stillman Drake, with a foreword by Giorgio de Santillana (New York: McGraw-Hill, 1965), 205–20; de Santillana's reply to Drake, appendix B to ibid., 221–25; and Langford, *Galileo, Science, and the Church*, 92–97.

35. Drake, *Discoveries and Opinions*, 227, judges this "the greatest polemic ever written in physical science." For a complete translation of *The Assayer*, see Stillman Drake and C. D. O'Malley, trans., *The Controversy on the Comets of 1618* (Philadelphia: University of Pennsylvania Press, 1960).

36. Fantoli, *Galileo*, 286.

37. de Santillana, *Crime of Galileo*, 166.

38. For examples, see Galileo's *Dialogue Concerning the Two Chief World Systems*, trans. Stillman Drake, 2d rev. ed. (Berkeley and Los Angeles: University of California Press, 1967), 53–54, 203. For more, including the judgment that "Galileo claims for the new science [which clearly includes heliocentric cosmology among its most notable achievements] an absolute monopoly on truth," see Brian Vickers, "Apodeictic Rhetoric in Galileo's *Dialogo*," in Paolo Galluzzi, ed., *Novità celesti e crisi del sapere, Atti del Convegno internazionale di studi Galileiani* (supplement to the *Annali dell'Istituto e Museo di Storia della Scienza*, no. 8 [1983]), 86. In a letter to a friend Galileo promised that his forthcoming *Dialogue* would contain "a most ample confirmation of the Copernican system"; see Fantoli, *Galileo*, 333.

39. Maurice A. Finocchiaro, *Galileo on the World Systems: A New Abridged Translation and Guide* (Berkeley and Los Angeles: University of California Press, 1997), 305–6.

40. Ibid., 306–7, slightly edited.

41. Fantoli, *Galileo*, 335–43.

42. Ibid., 389–91.

43. Finocchiaro, *Galileo Affair*, 229 (slightly edited), 231, 232.

44. Ibid., 230, with revisions.

45. Fantoli, *Galileo*, 413–21.

46. On Galileo's trial, see Fantoli, *Galileo*; Westfall, *Essays on the Trial of Galileo*; Biagioli, *Galileo Courtier*; Langford, *Galileo, Science, and the Church*; Blackwell, *Galileo, Bellarmine, and the Bible*; and de Santillana, *Crime of Galileo*.

47. Blackwell, *Galileo, Bellarmine, and the Bible*, 131, 133–34. On this issue, see also Maurice A. Finocchiaro, "Science, Religion, and the Historiography of the Galileo Affair: On the Undesirability of Oversimplification," *Osiris*, 2d ser., vol. 16 (2001), 114–32 (at 125–28).

48. Langford, *Galileo, Science, and the Church*, 143–44, slightly edited.

49. Finocchiaro, *Galileo Affair*, 280.

50. Ibid., 286, slightly edited.

51. Ibid., 291, slightly edited.

52. Ibid., 292, slightly edited.

53. On Dominican-Jesuit politics, see especially Feldhay, *Galileo and the Church*.

CHAPTER 3

1. There is a voluminous literature on the origins and development of the mechanical philosophy; the best introduction and survey is still E. J. Dijksterhuis, *The Mechanization of the World Picture*, trans. C. Dikshoorn (New York: Oxford University Press, 1961). A brief summary of seventeenth-century mechanical philosophy can be found in Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (Cambridge: Cambridge University Press, 1977), 25–42.

2. Other studies of the interaction between Christianity and the mechanical philosophy include Gary B. Deason, "Reformation Theology and the Mechanistic Conception of Nature," in David C. Lindberg and Ronald L. Numbers, eds., *God and Nature: Historical Essays on the Encounter between Christianity and Science* (Berkeley and Los Angeles: University of California Press, 1986), 167–91; Richard S. Westfall, *Science and Religion in Seventeenth-Century England* (New Haven: Yale University Press, 1958), esp. 70–105; E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science* (1924; rev. ed. 1932; reprinted Garden City: Doubleday, 1954).

3. The principal source on the skeptical crisis is Richard H. Popkin, *The History of Scepticism from Erasmus to Spinoza* (Berkeley and Los Angeles: University of California Press, 1979).

4. There are several good intellectual biographies of Descartes; one is Stephen Gaukroger, *Descartes: An Intellectual Biography* (Oxford: Clarendon Press, 1995); see also William R. Shea, *The Magic of Numbers and Motion: The Scientific Career of René Descartes* (Canton, Mass.: Science History Publications, 1991). A useful collection of essays on various aspects of Descartes's thought is John Cottingham, ed., *The Cambridge Companion to Descartes* (Cambridge: Cambridge University Press, 1992).

5. René Descartes, *Second Meditation*; translation based on *Philosophical Works of Descartes*, 2 vols., trans. Elizabeth S. Haldane and G. R. T. Ross (Cambridge: Cambridge University Press, 1911), 1:154; and Descartes, *Philosophical Writings*, trans. Elizabeth Anscombe and Peter T. Geach, rev. ed. (London: Thomas Nelson, 1970), 72.

6. The standard work on Descartes's cosmology is E. J. Aiton, *The Vortex Theory of Planetary Motions* (New York: American Elsevier, 1972); see esp. 43–64.

7. A good introduction to Aristotle's theory of substance is G. E. R. Lloyd, *Aristotle: The Growth and Structure of His Thought* (Cambridge: Cambridge University Press, 1968), 47–57. For a brief but quite clear discussion see David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450* (Chicago: University of Chicago Press, 1992), 48–51. Norma A. Emerton, *The Scientific Reinterpretation of Form* (Ithaca: Cornell University Press, 1984), provides an entire history of forms in Western thought; although focused on mineralogy, it contains many useful insights.

8. On Aristotle's elements, see Lloyd, *Aristotle*, 164–75.

9. On natural magic in the Renaissance, see Brian P. Copenhaver, "Natural magic, Hermetism, and Occultism in Early Modern Science," in David C. Lindberg and Robert S. Westman, eds., *Reappraisals of the Scientific Revolution* (Cambridge: Cambridge University Press, 1990), 261–302; John Henry, "Magic and Science in the Sixteenth and Seventeenth Centuries," in R. C. Olby et al., eds., *Companion to the History of Modern Science* (London: Routledge, 1990), 583–96; Ingrid Merkel and Allen G. Debus, eds., *Hermeticism and the Renaissance: Intellectual History and the Occult in Early Modern Europe* (Washington: Folger Shakespeare Library, 1988); Brian Vickers, ed., *Occult and Scientific Mentalities in the Renaissance* (Cambridge: Cambridge University Press, 1984); D. P. Walker, *Spiritual and Demonic Magic from Ficino to Campanella* (Nedeln: Kraus, 1969).

10. An English translation, *Natural Magick* (1658), has been reprinted in facsimile (New York: Basic Books, 1957).

11. On the church and natural magic, see William B. Ashworth Jr., "Catholicism and Early Modern Science," in Lindberg and Numbers, *God and Nature*, 136–66 (esp. 148–49).

12. Most of Fludd's diagrams of correspondences are reproduced in Joscelyn Godwin, *Robert Fludd: Hermetic Philosopher and Surveyor of Two Worlds* (London: Thames and Hudson, 1979). See also Eberhard Knobloch, "Harmony and Cosmos: Mathematics Serving a Teleological Understanding of the World," *Physis*, 32 (1995), 55–89.

13. There is an enormous literature on Descartes, God, and religion; see Gary Hatfield, "Reason, Nature, and God in Descartes," *Science in Context*, 3 (1989), 175–201; Jean-Marie Beyssade, "The Idea of God and Proofs of His Existence," in Cottingham, *Cambridge Companion to Descartes*, 174–99; Margaret J. Osler, "Eternal Truths and the Laws of Nature: The Theological Foundations of Descartes' Philosophy of Nature," *Journal of the History of Ideas*, 46 (1985), 349–62; Richard S. Westfall, "The Rise of Science and the Decline of Orthodox Christianity: A Study of Kepler, Descartes, and Newton," in Lindberg and Numbers, *God and Nature*, 218–37.

14. On ancient Greek atomism, see Dijksterhuis, *Mechanization*, 8–13; Stephen Toulmin and June Goodfield, *The Architecture of Matter* (New York: Harper and Row, 1962), 63–72. For a complete history of atomism, see Andrew Pyle, *Atomism and Its Critics: From Democritus to Newton* (Bristol: Thoemmes Press, 1997), which is thorough and valuable, though possibly difficult for the nonspecialist, owing to its use of the technical language of the historian of philosophy.

15. On Epicurus, see Lindberg, *Beginnings of Western Science*, 77–80.

16. Book-length studies of Gassendi include Barry Brundell, *Pierre Gassendi: From Aristotelianism to a New Natural Philosophy* (Dordrecht: Reidel, 1987); and Lynn Sumida Joy, *Gassendi the Atomist: Advocate of History in an Age of Science* (Cambridge: Cambridge University Press, 1987).

17. On Gassendi's atomism, see Dijksterhuis, *Mechanization*, 425–31; Daniel Garber, "Apples, Oranges, and the Role of Gassendi's Atomism in Seventeenth-Century Science," *Perspectives on Science*, 3 (1995), 425–28; and Margaret J. Osler, "Baptizing Epicurean Atomism: Pierre Gassendi on the Immortality of the Soul," in Margaret J. Osler and Paul L. Farber, eds., *Religion, Science, and Worldview: Essays in Honor of Richard S. Westfall* (Cambridge: Cambridge University Press, 1985), 163–83.

18. On the contrasting views of Descartes and Gassendi, see Margaret J. Osler, *Divine Will and the Mechanical Philosophy: Gassendi and Descartes on Contingency and Necessity in the Created World* (Cambridge: Cambridge University Press, 1994).

19. On Hobbes and the mechanical philosophy, see Robert H. Kargon, *Atomism in England from Hariot to Newton* (Oxford: Clarendon Press, 1966), 54–62; Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985); Simon Schaffer, "Wallifaction: Thomas Hobbes on School Divinity and Experimental Pneumatics," *Studies in History and Philosophy of Science*, 19 (1988), 275–98. On Hobbes and materialism, see Samuel I. Mintz, *The Hunting of Leviathan: Seventeenth-Century Reactions to the Materialism and Moral Philosophy of Thomas Hobbes* (Cambridge: Cambridge University Press, 1962), esp. 63–79. On Hobbes and religion, see Patricia Springborg, "Hobbes on Religion," in Tom Sorell, ed., *The Cambridge Companion to Hobbes* (Cambridge: Cambridge University Press, 1996), 346–80.

20. On More and the mechanical philosophy, see A. Rupert Hall, "Henry More and the Scientific Revolution," in Sarah Hutton, ed., *Henry More (1614–1687): Tercentenary Studies* (Dordrecht: Kluwer, 1990), 37–54; Alan Gabbey, "Henry More and the Limits of Mechanism," in ibid., 19–35; John Henry, "Henry More versus Robert Boyle: The Spirit of Nature and the Nature of Providence," in ibid., 55–76; Burtt, *Metaphysical Foundations*, 135–50.

21. For more detail on the attempts of More and Cudworth to refute Hobbesian materialism, see Mintz, *The Hunting of Leviathan*, 80–109.

22. On Cudworth, see J. A. Passmore, *Ralph Cudworth: An Interpretation* (Cambridge: Cambridge University Press, 1951); Alexander Jacob, "The Neoplatonic Conception of Nature in More, Cudworth, and Berkeley," in Stephen Gaukroger, ed., *The Uses of Antiquity: The Scientific Revolution and the Classical Tradition* (Dordrecht: Kluwer, 1991), 101–21; Alan Gabbey, "Cudworth, More, and the Mechanical Analogy," in Richard Kroll et al., eds., *Philosophy, Science, and Religion in England, 1640–1700* (Cambridge: Cambridge University Press, 1992), 109–27.

23. On Boyle's experimental science, see Shapin and Schaffer, *Leviathan and the Air-Pump*, esp. 22–79; Antonio Clericuzio, "The Mechanical Philosophy and the Spring of Air: New Light on Robert Boyle and Robert Hooke," *Nuncius*, 13 (1) (1998), 69–75.

24. Dijksterhuis, *Mechanization*, 433–44.

25. On Boyle and the mechanical philosophy, see Margaret J. Osler, "The Intellectual Sources of Robert Boyle's Philosophy of Nature: Gassendi's Voluntarism and Boyle's Physico-Theological Project," in Kroll, *Philosophy, Science, and Religion in England*, 178–98; Kargon, *Atomism in England*, 93–105; Peter Alexander, *Ideas, Qualities, and Corpuscles: Locke and Boyle on the External World* (Cambridge: Cambridge University Press, 1985); J. E. McGuire, "Boyle's Conception of Nature," *Journal of the History of Ideas*, 33 (1972), 523–42.

26. Boyle, "Notion of Nature," quoted in McGuire, "Boyle's Conception of Nature," 533.

27. Boyle, "Free Inquiry," quoted in Timothy Shanahan, "God and Nature in the Thought of Robert Boyle, *Journal of the History of Philosophy*, 26 (1988), 547–69 (on 558).

28. For more on Boyle's view of God and nature, see J. J. MacIntosh, "Robert Boyle's Epistemology: The Interaction between Scientific and Religious Knowledge," *International Studies in the Philosophy of Science*, 6 (1992), 91–121; Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge: Cambridge University Press, 1997); Shanahan, "God and Nature"; Osler, "Intellectual Sources."

29. On Boyle and natural theology, see Westfall, *Science and Religion in Seventeenth-Century England*.

30. On Boyle and miracles, see J. J. MacIntosh, "Locke and Boyle on Miracles and God's Existence," in Michael Hunter, ed., *Robert Boyle Reconsidered* (Cambridge: Cambridge University Press, 1994), 193–214.

31. The best introduction to all aspects of Newton's life and thought is the magisterial Richard S. Westfall, *Never at Rest: A Biography of Isaac Newton* (Cambridge: Cambridge University Press, 1980).

32. Walter Charleton was the English physician primarily responsible for introducing

Gassendi to England, through the publication of his *Physiologia Epicuro-Gassendo-Charltoniana* (1654), which, in spite of its formidable Latin title, was written in English. Charleton attempted to show that atomism does not necessarily lead to Hobbes's materialism, and Charleton was one of the first to argue that the mechanical philosophy can actually promote Christianity. For a good discussion of Charleton, see Kargon, *Atomism in England*, 84–89.

33. Westfall, *Never at Rest*, 83–104.

34. Christiaan Huygens, a brilliant Dutch mathematician, invented the first accurate pendulum clock, discovered the law of the pendulum, and worked out, before Newton, the law of centrifugal force. He took his mechanical philosophy from Descartes, and although he had many differences with Descartes, he believed that impact was the source of all motion. He worked out his own vortex theory of gravity, published in 1690. For detail on Huygens's opposition to Newtonian gravity, see H. A. M. Snelders, "Christiaan Huygens and Newton's Theory of Gravitation," *Notes and Records of the Royal Society of London*, 43 (1989), 202–22; Roberto de A. Martins, "Huygens's Reaction to Newton's Gravitational Theory," in J. V. Field and Frank A. J. L. James, eds., *Renaissance and Revolution: Humanists, Scholars, Craftsmen, and Natural Philosophers in Early Modern Europe* (Cambridge: Cambridge University Press, 1993), 203–13.

35. See John Hedley Brooke, "The God of Isaac Newton," in John Fauvel et al., eds., *Let Newton Be!* (Oxford: Oxford University Press, 1988), 169–83; Frank E. Manuel, *The Religion of Isaac Newton: The Fremantle Lectures*, 1973 (Oxford: Clarendon Press, 1974); E. A. Burtt, *Metaphysical Foundations*, 283–302.

36. James E. Force, "Newton's God of Dominion: The Unity of Newton's Theological, Scientific, and Political Thought," in James E. Force and Richard H. Popkin, *Essays on the Context, Nature, and Influence of Isaac Newton's Theology* (Dordrecht: Kluwer, 1990), 75–102.

37. On Newton and active principles, see J. E. McGuire, "Force, Active Principles, and Newton's Invisible Realm," *Ambix*, 15 (1968), 154–208; Ernan McMullin, *Newton on Matter and Activity* (Notre Dame: University of Notre Dame Press, 1978); John Henry, "Newton, Matter, and Magic," in Fauvel et al., *Let Newton Be!*, 127–46; Alan Gabbey, "Newton and Natural Philosophy," in Olby et al., *Companion to the History of Modern Science*, 243–63 (esp. 258–62).

38. In 1715–16, Leibniz exchanged a series of letters with Samuel Clarke (who spoke for Newton), in which they disputed such matters as the nature of space, time, and God's relationship to his Creation. This correspondence, published in 1717, can be consulted in H. G. Alexander, ed., *The Leibniz-Clarke Correspondence, Together with Extracts from Newton's Principia and Opticks* (Manchester: Manchester University Press, 1956); see p. 11 for Leibniz's comment about Newton's God having to wind up his Creation.

CHAPTER 4

1. Peter Gay, *The Enlightenment: An Interpretation*, vol. 1, "The Rise of Modern Paganism" (New York: Norton, 1977), 339.

2. Gay, *The Enlightenment: An Interpretation*, vol. 2, "The Science of Freedom" (New York: Norton, 1977), 8.

3. Gay, *The Enlightenment*, 1:338.

4. Voltaire, *Letters on England*, trans. with an intro. by Leonard Tancock (London: Penguin, 1980), 70.

5. Edward Gibbon, *The History of the Decline and Fall of the Roman Empire*, with notes by the Rev. H. H. Milman (Philadelphia: Porter & Coates, 1845), 1:550 n. 96. Beyond the attractions offered by Gibbon's sparkling prose, this particular edition also features a large number of apoplectic and outraged notes appended to the text by Milman.

6. Jean-Antoine-Nicolas de Condorcet, *Sketch for a Historical Picture of the Progress of the Human Mind*, trans. June Barraclough with an intro. by Stuart Hampshire (London: Weidenfeld and Nicolson, 1955), 72.

7. Immanuel Kant, *Critique of Pure Reason*, trans. Norman Kemp Smith (New York: St. Martin's, 1965), 9 n.

8. We would do well to remember that Christian belief was not alone in coming under critical scrutiny in the Enlightenment. Judaism too experienced a critical reform movement, known as the Haskalah, during the period. See David Sorkin, *Moses Mendelssohn and the Religious Enlightenment* (Berkeley and Los Angeles: University of California Press, 1996).

9. On the Leibniz-Clarke debate, see Steven Shapin, "Of Gods and Kings: Natural Philosophy and Politics in the Leibniz-Clarke Disputes," *Isis*, 72 (1981), 187–215; and Larry Stewart, *The Rise of Public Science: Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660–1750* (Cambridge: Cambridge University Press, 1992), 87ff.

10. Quoted in Gary B. Deason, "Reformation Theology and the Mechanistic Conception of Nature," in David C. Lindberg and Ronald L. Numbers, eds., *God and Nature: Historical Essays on the Encounter between Christianity and Science* (Berkeley and Los Angeles: University of California Press, 1986), 184. Deason's article is an excellent summary of the theological issues involved with the new natural philosophy of the seventeenth century.

11. John Locke, *An Essay Concerning Human Understanding*, bk. 2, chap. 21.

12. Jean d'Alembert, *Traité de dynamique*, quoted in Mary Terrall, "The Culture of Science in Frederick the Great's Berlin," *History of Science* (1990), 28:333–64, quoted on 355.

13. Terrall, "The Culture of Science in Frederick the Great's Berlin," esp. 353–58.

14. Quoted in Virginia Dawson, *Nature's Enigma: The Problem of the Polyp in the Letters of Bonnet, Trembley, and Réaumur* (Philadelphia: American Philosophical Society, 1987), 96–97.

15. See Elizabeth Gasking, *Investigations into Generation, 1651–1828* (Baltimore: Johns Hopkins University Press, 1967), and John Farley, *The Spontaneous Generation Controversy from Descartes to Oparin* (Baltimore: Johns Hopkins University Press, 1977).

16. Friedrich Hoffmann, *Fundamenta medicinae*, trans. and intro. Lester S. King (London: Macdonald, 1971), 5, 7.

17. Hermann Boerhaave, *Institutiones medicae* (Leiden, 1730), sec. 40, pp. 12–13. The translation is taken from *Dr. Boerhaave's Academical Lectures on the Theory of Physick*, 6 vols. (London, 1742–46), 1:81.

18. Quoted in Shirley A. Roe, *Matter, Life, and Generation: Eighteenth-Century Embryology and the Haller-Wolff Debate* (Cambridge: Cambridge University Press, 1981), 1.

19. Charles Bonnet, "Expériences sur la régénération de la tête du limaçon terrestre," *Observations sur la physique, sur l'histoire naturelle et sur les arts* (1777), 11:165–79.

20. Pierre-Louis de Maupertuis, *The Earthly Venus*, trans. Simone Brangier Boas, with notes and an intro. by George Boas (New York: Johnson Reprint, 1966), 56.

21. Roe, *Matter, Life, and Generation*, 15–20. See also Jacques Roger, *Buffon*, trans. Sarah Lucille Bonnefoi, ed. L. Pearce Williams (Ithaca: Cornell University Press, 1997), 139–50.