1. What To Do With the Mechanical Philosophy?

1.1 A Problematic Category

The mechanical philosophy that emerged during the Scientific Revolution can be defined *prima facie* as a reductionism according to which all physical phenomena are to be explained in terms of corpuscles of different sizes, shapes, and motions.[1] It provided early modern natural philosophers with a unified view of nature that contrasted primarily with the Aristotelian view of nature, but also with other naturalist, hermetic, mystic, occultist, Paracelsian, and chymical accounts. Indeed, early modern natural philosophers devised mechanical explanations of almost every kind of phenomena, such as gravity, magnetism, chemical operations, the fermentation of grapes, the colors of the rainbow, the circulation of the blood, the motion of the heart, and the development of animals. Even supranatural phenomena, such as transubstantiation, or phenomena today described as paranormal, like the action of sympathetic powder on a wound, the influence of the stars on terrestrial events, or the identification of thieves with a divining rod, were given mechanical explanations.[2]

Confronting this explanatory deluge, historians adopted two opposing narratives.[3] In "The Establishment of the Mechanical Philosophy," Marie Boas characterized early modern mechanical philosophy as "putting the atom to work."[4] According to her, Bacon, Descartes, and Galileo resurrected Ancient atomism; Boyle grafted the experimental method onto their ontological program; and Newton articulated the achievements of his predecessors into mathematical laws. In Boas's continuous narrative, the ontology of matter and motion is congenial to experimental investigation of nature and to a mathematized exposition of knowledge. Yet, two years before Boas's article, Eduard Jan Dijksterhuis had concluded that the key factor was not the ontology of machines, but the mathematized science of motion, so that, contrary to the title of his book, one should speak of a "mathematization" rather than of a "mechanization" of the world picture.[5] Richard Westfall similarly contrasted the corpuscular tradition, in which nature is conceived as a huge machine, with the Platonic-Pythagorean

[1] In this chapter, I draw from (Roux 1996; Roux 2004; Roux 2012; Roux 2017).

[2] (Digby 1658; Gadroys 1671; Vallemont 1693; Armogathe 1977; Nadler 1988; Del Prete 2001; Vermeir 2011)

[3] (Roux 2017, 31-33)

[4] (Boas 1952, 520)

[5] (Dijksterhuis 1961, 4, 495-500)

tradition, which flourished in mechanics and other mathematized sciences.[6] More bluntly than Dijksterhuis, he castigated Descartes and his corpuscularian fellows for indulging in the construction of imaginary mechanisms and for perpetuating obscure doctrines in domains like chemistry or medicine.

Surely there was an evolution from Boas's continuous narrative to Westfall's point that Newton had to resolve a tension between two conflicting traditions. Except in Boas's paper, the mechanical philosophy was never used by historians of the early modern period without qualification. Nevertheless, whether it was regarded as the ontological foundation of the Scientific Revolution or as a tradition that had to be surmounted, it was viewed as a well-identified category that captured something about early modern natural philosophy. The critical narratives of the last thirty years, however, have deconstructed both the belief that it is an adequate historical category and the conviction that it made a positive contribution to the sciences.

First, in an era that privileged microscopic case studies over sweeping panoramas, and emic over etic categories, 'mechanical philosophy' came to be thought of as lacking any real descriptive significance. It was pointed out that early modern natural philosophers took such complex positions that the frontiers between mechanical philosophers, Aristotelians, and chymists are difficult to draw in practice. Defenders of *minima naturalia* were Aristotelian corpuscularians; conceptual intersections developed between Aristotelians and followers of chymical doctrines; historical links existed between chymists and corpuscular philosophers.[7] The category was also suspected of being unable to account for the various positions actually defended by so-called mechanical philosophers. Helen Hattab, refusing to take Boyle's "rather unique amalgam" as exemplary, insisted on their differences: Descartes was engaged in a foundationalist quest for metaphysical certitude, while Marin Mersenne developed a mitigated scepticism; Pierre-Sylvain Régis considered animals as pure machines, while Claude Perrault attributed to them a directing soul; Boyle was optimistic that sensible qualities could be reduced to mechanical affections, while Locke's epistemology precluded such a reduction.[8] Daniel Garber argued that, while the category of the mechanical philosophy unified Boyle and his contemporaries, this was not so for the *novatores* at the beginning of the century.[9] Lastly, the conceptual identity of the mechanical philosophy began to be blurred. Should it be defined only by corpuscular reductionism, as at the beginning of this chapter? Or should we insist on the

[6] (Westfall, 1, 36, 42, 120)

[7] (Newman 1996; Clericuzio 2000; Murdoch 2001; Newman 2001; Newman 2006)

[8] (Hattab 2011)

[9] (Garber 2013) See also below.

elimination of life and soul? On the abolition of the boundaries between artificial and natural beings? On the impossibility of action at a distance? On the rejection of final causes? On the distinction between primary and secondary qualities? Or, still, rather than concentrating on ontological constraints, should we follow an epistemological thread and focus on the claim of the mechanical philosophers that their explanations are clear and intelligible, while Scholastic explanations are obscure and confused?[10]

Second, from an evaluative point of view, it has been claimed that the mechanical philosophy had no impact on the development of the new sciences. As noted, Westfall doubted its value outside of mechanics. Putting some historical flesh on Gaston Bachelard's claim that Descartes should be left in historical isolation because there are neither measures nor equations in his physics,[11] Yves Gingras argued that Newton transformed the notion of explanation by considering that mathematizing a phenomenon was sufficient to explain it. Far from reinforcing mechanization, as Dijksterhuis claimed, mathematization effaced the substances appearing in mechanical explanations.[12] Similarly, with regards to the association between mechanical philosophy and experimental practices, Antonio Clericuzio took issue with the idea that Boyle subordinated chemistry to mechanical philosophy, arguing that his corpuscles were endowed with chemical, not mechanical properties.[13] Contrary to Boas, Alan Chalmers moreover described the link between mechanical philosophy and experimentation as a union *against* nature. Boyle's experimental successes were "achieved in spite, rather than because, of his allegiance to mechanical philosophy."[14] In a word, the mechanical philosophy was said to have—at best—contextual value as a rhetorical meta-discourse designed to legitimize scientific practices.[15]

Considering these descriptive and evaluative challenges, taking the mechanical philosophy at face value is historically inadequate and philosophically naïve. Hence the questions addressed in this chapter: What to do with the mechanical philosophy? Does it have to be dropped completely as a category? And, if not, how is it to be used? My view is that it captures something of the transformations that we put under the umbrella of the Scientific Revolution,

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[10] (McGuire 1972, 523; Pyle 1995, 506-508; Roux 1996, 32-33, Gabbey, 2002; Gabbey 2004, 15)

[11] (Bachelard 1951, 35)

[12] (Gingras 2001; Gingras 2002) See also (Gaukroger 2006, 402-403).

[13] (Clericuzio 1990) See also (Clericuzio 2000, 103-148).

[14] (Chalmers 1993, 541) (Chalmers 2002, 192) grants to (Pyle 2002) that he did not prove that the mechanical philosophy obstructed experimental practices and retreats to the weaker thesis that the first did not promote the second.

[15] (Gabbey 1985, 13-14; Clarke 1989, 189-190; Gabbey 1990a, 279; Gaukroger 2006, 253-255, 260, 397-406)

but that it is not possible to treat it as a naturally given category. Rather, to be employed usefully, it needs conceptual clarification and historical specification.

1.2 Uses of the Term 'Mechanical Philosophy'

One difficulty with the concept is the variation in the use of 'mechanical philosophy' across both time and place. *Some specimens of an attempt to make chymical experiments useful to illustrate the notions of the corpuscular philosophy*, which Robert Boyle wrote in the late fifties and published in *Certain Physiological Essays* (1661), is a usual place to begin. In the Preface, Boyle insisted that, notwithstanding the differences between their philosophies, the Cartesian and the atomist hypotheses "might be look'd upon as one Philosophy" because both endeavour "to explicate things intelligibly" and to "deduc[e] all the Phenomena of Nature from Matter and local Motion." At this point, he needed a term to baptize the philosophy that Descartes and Epicurus shared. He actually proposed several names: 'Corpuscular' because it explains natural phenomena through corpuscles; 'Mechanical' because it gives an account of phenomena by motion, which is "obvious and very powerfull in Mechanical Engines"; or 'Phoenician' because its first promoter was the Phoenician Moschus.[16] In one of his last books, *The Christian Virtuoso* (1690), Boyle enumerated the many adjectives used to designate the philosophy of the modern *virtuosi*: it was called the "New," the "Corpuscularian," the "Real," the "Atomical," the "Cartesian" or the "Mechanical" philosophy.[17] As for him, his most common adjectives were "corpuscular" (or "corpuscularian") and "mechanical," which he often presented as synonymous, though there is a nuance between them, the former concentrating on the entities that appear in explanations, the latter on the activities that these entities are engaged in.[18] And to "philosophy," he obviously preferred "hypothesis," to emphasize that it was not established once and for all, but only the best hypothesis that was then available.

From a purely terminological point of view, however, *Some specimens* was not the very beginning—the term 'mechanical philosophy' was used before 1660, initially as a pejorative. After he read *Meteors* and *Dioptrics*, Libert Froidmont complained that Descartes's composition of Aristotelian elements from small parts of various shapes was "too gross and mechanical

[16] (Boyle 1999-2000, 2:87), discussed in (Roux 1996, 18-20; Gabbey 2004, 16-17; Garber 2013, 6-8). See also (Boyle 1999-2000, 2:260; 5:302; 6:267; 6:455).

[17] (Boyle 1999-2000, 11:292)

[18] The book Henry Oldenburg publicized in the *Philosophical Transactions* as "a kind of *Introduction* to the Principles of the *Mechanical Philosophy*" (1666, p. 191) bears the title *The Origin of Forms and Qualities according to the Corpuscular Philosophy* on its front cover and "The Origin of Forms and Qualities according to the Corpuscular *or Mechanical* Philosophy" on its first page. "Corpuscular(ian)" and "mechanical" are used as synonymous in (Boyle 1999-2000, 5:288; 8:32, 89; 9:38, 286). See also (Cudworth 1678, 10-11, 25, 27, 39, 48, 51-52).

[*nimis crassa et mechanica*]."[19] For the Aristotelian Froidmont, calling a natural philosophy 'mechanical' revealed the category mistake Descartes had committed: natural philosophy deals with natural beings, so it has nothing to do with artificial things like machines, which were the domain of a mixed mathematical science. The characterization also invited contempt for Descartes's philosophy, just as one might disdain coarse and brutish mechanics working with their hands. A few years later, Henry More also identified the "mechanical philosophy" in order to reject it, dubbing Descartes "the great Master of this Mechanicall Hypothesis" and "pretender to Mechanick Philosophy."[20] Unabashed, Descartes adopted 'mechanical' as a badge of honor and claimed that it was only in as much that his philosophy deals with figures, magnitudes, and motions that it is certain, because this amounts to "a kind of philosophy, where no reasoning is used which is not mathematical and evident, and the conclusions of which are all supported by very certain experiences." Rejecting the Aristotelian distinction, Descartes asserted the equivalence of physics and mechanics,[21] and claimed that "my bloated and mechanical philosophy [*pinguiscula & mechanica philosophia mea*]" could solve many more problems than other natural philosophies.[22]

That there were some polemical uses of 'mechanical philosophy' before Boyle does not mean that he did not play an important role. Partly because of his prominence and partly because the program of explaining phenomena in terms of matter and motion was already established in England, the terms 'corpuscular philosophy' and 'mechanical philosophy' were quite successful there, even among the adversaries of this philosophy. In his obstinate crusade against the "pure" and "mere" mechanical philosophy, More actually contributed to the term's popularity as much as Boyle.[23] The adjectives 'mechanical' and 'experimental' were regularly paired together, as if each of them helped make the meaning of the other more precise. Henry Power, for example, opposed "the old Dogmatists and Notional Speculators" to "the Experimental and Mechanical philosopher," who is able "to find the various turnings, and mysterious process of this divine Art, in the management of this great Machine of the World."[24] Likewise, Robert Hooke contrasted "the Philosophy of discourse and disputations" with "the *real*, the *mechanical*, the *experimental Philosophy*," and Samuel Parker explained that the mechanical and experimental philosophy was to be preferred to the Aristotelian philosophy.[25]

[19] (Descartes 1964-1974, 1:402-406)

[20] (Descartes 1964-1974, 11:243) (More 1662, 44) and (More 1659) discussed in (Gabbey 1982, 220-222).

[21] (Descartes 1964-1974, 1:524; 2:212, 542)

[22] (Descartes 1964-1974, 1:420-421, 430), discussed in (Roux 1996, 15-17; Gabbey 2004, 12-20; Roux 2004, 32-34).

[23] (More 1659, 11-13; More 1671, sig. B1v and 223, 301, 307-308; Gabbey 1990b, 26-27)

[24] (Power 1664, 193)

[25] (Hooke 1665, sig. a2r; Parker 1666, 41, 45) See also (Hooke 1674, 16).

The association also appeared in attacks on the Royal Society's *virtuosi*, such as those by Margaret Cavendish and Henry Stubbe.[26]

This link between 'mechanical' and 'experimental' might be puzzling. For the modern reader, these terms are not directly related, the first referring to a theory of matter; the second, to a method of inquiring. It is all the more intriguing that 'corpuscular' and 'atomical' were associated with 'mechanical', as in Boyle, but (to the best of my knowledge) never paired with 'experimental'. The solution comes from the polysemy of the English word 'mechanical' in the period. It referred not only to machines and to the science of mechanics, but also to what is related to manual labor, practical skills, artisanal instruments, and concrete operations.[27] The experimental philosophy is "mechanical" in this sense.[28] But there was no similar reason for the experimental philosophy to be called 'corpuscular'.

Continental terminology was quite different. Even those who thought that all natural phenomena have to be explained through matter and motion did not use 'mechanical philosophy' frequently, and, when they did, they did not associate it with experiments.[29] Leibniz's writings also testify that the use of 'mechanical philosophy' on the Continent resulted from the impact of the Royal Society. When presenting the program of explaining all physical phenomena through corpuscles of different sizes, figures, and motions, the young Leibniz generally attributed it to "the moderns [*recentiores*]," "the new philosophers [*novatores*]," or the partisans of a "reformed" or "restored" philosophy, conceived as a return to Aristotle.[30] Only in reference to the English *virtuosi* does he speak of "corpuscularians" and of "corpuscular philosophy."[31] From the end of the 1670s, Leibniz continued to use 'corpuscular philosophy' occasionally,[32] but more frequent were 'mechanical philosophy' and 'mechanism', that he understood as a general view of nature.[33] Even if he still occasionally interchanged 'mechanical' with 'corpuscular',[34] he more regularly associated the former term with mechanics, understood

[26] (Stubbe 1670, 4, 6; Cavendish 2001, 49, 74, 93)

[27] (Roux 1996, 7-8; Gabbey 2004, 12-14; Roux 2004, 31-33) See also (Bennett 1986).

[28] (Sprat 1667, 336, 340)

[29] See, e.g., (Vanzo 2016; Vanzo 2017).

[30] (Leibniz 1923-, 2-1:1, 18-19, 25-26, 29-30, 33-34, 266)

[31] (Leibniz 1923-, 6-1:489-490; 6-2:325, 327)

[32] (Leibniz 1923-, 2-2:396, 845; 6-4: 477)

[33] (Leibniz 1923-, 2-2:172; 6-4:485, 1559, 1566, 2009, 2118, 2342)

[34] (Leibniz 1923-, 2-2:122, 343, 396; 2-3:100; 6-2:325; 6-4:722, 2039)

as the geometrical science that formulates laws of motion.[35] Thus, 'mechanical' is not associated with 'experimental', but connotes necessary chains of mathematical demonstrations.[36]

The semantic connotations are similar in Bernard Le Bovier de Fontenelle. At the beginning of his *Entretiens sur la pluralité des mondes* (1686), he imagined the philosopher as an engineer (*machiniste*) who attends a play and tries to figure out how the spectacle is produced. Phaeton rises into the air; ancient philosophers venture ridiculous explanations, but the Moderns use the principle that a body cannot move except by contact with another body. This prompted one of the rare uses of 'mechanical philosophy' in French, where one can still hear an echo of Froidmont's scorn: "I perceive, *said the Marchioness*, Philosophy is now become very mechanical. So mechanical, Madam, *said I*, that I fear we shall quickly be asham'd of it."[37] Here, 'mechanical philosophy' refers to explanations that compare natural phenomena to machines and are intelligible because they involve only contact actions. The association of mechanical and intelligible also colors the eulogies Fontenelle wrote as secretary of the *Académie des Sciences*. Defending the corpuscular philosophy against Martino Poli's objections, he defined it as the one "where only clear ideas are admitted, that is figures and motions."[38] Fontenelle also praised Domenico Guglielmini for having undertaken "to reduce this mysterious chemistry to the simple corpuscular mechanics," approving in particular his attempt to explain the properties of salts "geometrically and mechanically."[39]

This terminological enquiry showed how the term 'mechanical philosophy'—an oxymoron for Aristotelians—became a common banner under which early modern philosophers rallied, especially in England, where it was joined to experimental philosophy. It also shows that those who wrote in French were more cautious in their use of the terms 'mechanical philosophy' and 'corpuscular philosophy', and associated them with the necessity and intelligibility of mathematics. At this point, we are confronted with a classical problem for the intellectual historian; namely, the relation between emic and etic categories—i.e., the words used by those who are studied and the words used by scholars to study them. Should we restrict our enquiry to authors who explicitly designated themselves as mechanical philosophers? Or should we admit that there were mechanical philosophers who did not use the term?

[35] (Leibniz 1923-, 2-1: 789; 2-2:82-83, 90, 318, 343, 396, 816; 6-4)

[36] See also (Hoffmann 1699, sig. B2r-v).

[37] (Fontenelle 1737, 7-10)

[38] (Fontenelle 1740, 1:321-322)

[39] (Fontenelle 1740, 1:250, 252)

Inclining to the former view, Daniel Garber thinks that even if Hobbes, Gassendi, and Descartes subscribed to the mechanical view, they are better described as *novatores* who were competing in a race for a new natural philosophy that would supersede Aristotle's; and it was only once Boyle had popularized the term 'mechanical philosophy' that natural philosophers were able to adopt a common paradigm.[40] Garber indeed captures something of the difference between the early seventeenth century, when each philosopher criticized the dominant Aristotelianism in his own name, and the late seventeenth century, when collective institutions stabilized the main tenets of the new philosophy. But no paradigm has ever perfectly unified philosophers. Even after 1660, natural philosophers—mechanical philosophers among them—disagreed about most issues. Moreover, since the term 'mechanical philosophy' was far less used on the Continent though mechanical philosophers were no less common, the presence of the former is not a reliable indicator of the latter.

Last but not least, it is important not to confuse the use of words with the things they refer to. As he himself acknowledged, Boyle did not create the mechanical philosophy out of nothing; there had been already many attempts to formulate a natural philosophy in terms of matter and motion. While recognizing that the popularization of the term 'mechanical philosophy' is historically significant, one should resist terminological fetishism and insist that it captures already existing elements, without which there would have been nothing to name. This is why in what follows, the term 'mechanical philosophy' is used as an etic category—it is applied not only to those who described themselves as mechanical philosophers, but extended to anyone who tried to reduce physical phenomena to corpuscles of different sizes, shapes, and motions.

1.3 Articulating the Variety of Mechanical Philosophies

Once the category of the mechanical philosophy has been thus extended, the historian encounters yet another problem, which is that it now seems much too broad to be helpful. Must one examine each early modern "mechanical philosophy" individually? That would be tedious, but it would also miss an essential feature: "mechanical philosophy" was a polemical category put forward *against* other natural philosophies. This observation offers a means for introducing conceptual distinctions in the *mare magnum* of mechanical philosophies. Controversies made explicit what mechanical philosophers expected from their own explanations, and their rejection of alternatives makes their variety manifest.[41] In what follows, I study three such controversies

[40] (Garber 2013) See also his chapter in this volume and (Gabbey 2004, 14-21).

[41] For another categorization insisting on the distinction between the corpuscular philosophers who reduced physical phenomena to corpuscles endowed with various qualities and the mechanical philosophers who attributed to them only

to identify various kinds of mechanical philosophy, or if one prefers, various uses of 'mechanical philosophy': the controversy about the motion of the heart (Descartes versus Plempius); the controversy about the elasticity of the air (Boyle versus More); and the controversy about the universal attraction of bodies (Huygens and Leibniz versus Newton).

1.3.1 Descartes versus Plempius about the motion of the heart: mechanical explanations are contrasted with obscure faculties and display necessary sequences of motions

Recent studies have recognized the importance of his natural philosophy for Descartes,[42] and his project is often described as aiming at reducing all physical phenomena to corpuscles moving according his three laws of motion.[43] Yet a more complex picture emerges from the concrete explanations he suggested, as shown by his exchanges on the circulation of the blood and motion of the heart.

In all of his writings, Descartes praised William Harvey for the discovery of the circulation of the blood.[44] Yet, from his early treatise *De l'homme* (1633, published posthumously in 1664), he was adamant that, contrary to what Harvey pretended, the motion of the heart had to be explained by a sequence of motions provoked by the extreme heat of the heart, which he conceived as "a fire without light," similar to the fires that are kindled in inanimate bodies.[45] Specifically, the beating of heart and arteries arises from the expansion of blood by the innate fire as it passes through the cardiac chambers and into the vessels. Descartes insisted that this sequence of motions follows as necessarily from the heat and from the disposition of organs as the motion of a clock would follow from the force and configuration of its counterweights and wheels.[46] While defending his "bloated and mechanical philosophy" against Froidmont, he asked Fortunatus Plempius—professor of medicine at Leuven—what he thought of his explanation.[47] The ensuing correspondence led him to make explicit that explaining the functions of the body requires "no vegetative or sensitive soul or any other principle of motion and life".[48]

geometrical properties, so that Boyle is a corpuscular philosopher without being a mechanical philosopher, see (Clericuzio 1990; Clericuzio 2000).

[42] (Clarke 1982; Garber 1992; Gaukroger 1997; Gaukroger, et al. 2000; Ariew)

[43] (Clarke 1982, 122-125; Gaukroger 1997, 94-96, 171-173)

[44] (Descartes 1964-1974, 6:50-51; 11:239-240) See (Descartes 1964-1974, 4:4, 189, 700). On what follows, see (Gilson 1951; Bitbol-Hespériès 1990; Grene 1993; Petrescu 2013; Hutchins 2015; Ragland).

[45] (Descartes, 6:46; 11:123-124, 407) See also (Descartes 1964-1974, 4:189, 686).

[46] (Descartes 1964-1974, 6:50, 11:202)

[47] (Descartes 1964-1974, 1:411, 477)

[48] (Descartes 1964-1974, 11:208)

In his answers to Descartes, Plempius quickly came to concede that he could approve of the circulation of the blood.[49] He maintained however that physicians had good reasons to prefer Galen's (and Harvey's) view that the heart is moved by a vital faculty. Among these, two prompted interesting replies from Descartes. First, Plempius wrote, the heart goes on beating when it is removed from the body and cut into pieces, and no blood enters or exits it. Second, as Galen demonstrated, if a tube is introduced into an artery, the artery does not beat below the tube, although blood still passes through it.[50]

Descartes suggested different hypotheses to explain how the bits of an eviscerated heart go on beating—some blood might remain, which could be sufficient to make the tissue dilate, all the more if some ferment lies in its folds. Turning the tables, he added that Plempius's objection is stronger against those who believe that a faculty of the soul makes the heart beat. According to them, the rational soul is indivisible and distinct from the vegetative and sensitive souls, so it cannot cause pieces of the heart separated from the body beat.[51] In reply, Plempius suggested that the common doctrine could be saved by saying that it is not the rational soul itself that resides in the bits of heart, but its instrument—that is, a spirit that acts according to the power of the soul even if the soul itself is not around.[52] This prompted Descartes to point out that, since Plempius is ready to recognize that these spirits can act even in the absence of the soul—when one is dead—he should recognize that they do not need it even when it is present—when one is alive.[53] In a word, if a physiological phenomenon can be explained without resorting to the soul, then the soul is superfluous. This is an appeal to ontological parsimony, which Descartes invoked more generally in this period, in two complementary ways: first, once a mechanical explanation is given, other entities are not needed;[54] and second, when several explanations are available, the mechanical one requires the least entities.[55]

To Plempius's second objection, Descartes replies that "the laws of mechanics, that is of [his] physics" could account for Galen's experiment. The blood passing from the channel narrowed by the tube to a wider vessel does not have enough force to make the arteries beat.[56] Plempius's faculty is arguably replaced by the laws of mechanics. Yet it should be noted that

[49] (Descartes 1964-1974, 2:54) On Plempius's conversion, see (Petrescu 2013, 407-410).

[50] (Descartes 1964-1974, 1:497-498)

[51] (Descartes 1964-1974, 1:523) Fermentation does not depart from mechanical principles: like dilatation, it results from motion.

[52] (Descartes 1964-1974, 2:52)

[53] (Descartes 1964-1974, 2:65)

[54] *Le Monde* (Descartes 1964-1974, 11:7, 26)

[55] (Descartes 1964-1974, 2:200; 3:215)

[56] (Descartes 1964-1974, 1:527)

there is no corpuscular reduction here, and that the qualitative principle at work—the wider the tube through which a liquid passes, the less force it has—cannot be derived directly from Descartes's fundamental laws of motion. Rather, one must add the given structure (the sequence of two tubes, the first one narrower than the second one) to the laws to explain the phenomenon. This can be generalized to the other passages where Descartes invokes laws of mechanics in a physiological context. His three laws of motion do not explain by themselves the phenomena at hand, but have to be applied to specific structures.[57]

These conclusions are reinforced by an additional criticism of Harvey's account Descartes later developed. According to Descartes, Harvey wrongly claimed that the dilation of the cavities of the heart leads to the admission of blood, while their contraction leads to its emission.[58] The argument here is not inspired by ontological parsimony, but by a requirement of intelligibility. The trouble is that, on Harvey's account, the motion of the heart is the cause, not a consequence, of the motion of the blood, so one is obliged to make a faculty account for it, "the nature of which is much more difficult to conceive than everything that he pretends to explain through it."[59] Supposing a faculty of contraction without saying how it works does not explain the contraction, the *explanans* duplicates the *explanandum*. On the contrary, Descartes claims, his own explanation is "deduced" "only from the heat [of the heart] and from the conformation of its cavities," "according to the laws of mechanics," all these things being "truthfully mechanical."[60]

Without detailing this correspondence further, let us conclude that Descartes presented his explanation of the motion of heart as mechanical because it results from a necessary sequence of motions determined by the structure of the heart and, more generally, by the system of the human body. Such a structural explanation does not result from a reduction to corpuscles, the motion of which would be directly determined by the three laws of nature, but appeals to higher-level entities, like flesh, pores, or fibers, and higher-level operations like the lengthening of the heart that causes the expulsion of blood. One might now ask about the relationship between such a structural explanation and a full-blown reductionist explanation. Most commentators, while acknowledging the distinction, maintain that the former will eventually result in the latter.[61] Others argue that Descartes may have faltered upon reaching the outer

57 (Descartes 1964-1974, 4:5; 6:54)

58 (Descartes 1964-1974, 1:527; 4:4; 11:241-243) In this letter to Plempius, systole and diastole seem to be confused.

59 (Descartes 1964-1974, 11:243)

60 (Descartes 1964-1974, 4:4-5)

61 (Des Chene 2001, 71-72, 83-89, 154; Roux 2004, 34)

branches of his tree of knowledge.[62] However, it is imperative to keep in mind that the distinction between structural and reductionist explanations exists for neither Plempius nor Descartes. The only relevant question for both of them was whether faculties can be dispensed with in favor of motions. Descartes concluded that the answer to this question was affirmative, because of a principle of parsimony and of a principle of intelligibility, which were convergent according to him.

1.3.2 Boyle versus More about the spring of the air: mechanical explanations are contrasted to immaterial principles and imply experimental properties

As we have already noted, it was important for Boyle to define a program to which a significant number of natural philosophers could subscribe. In *The Origin of Forms and Qualities According to the Corpuscular Philosophy* (1666), he identified more precisely its fundamental tenets.[63] He held that the physical world is made of corpuscles. When clustered into molecules, the corpuscles gain a posture, order, and situation in relation to one another, which Boyle calls a texture.[64] What humans call the sensible qualities are in reality impressions made on our senses by various textures, and forms are nothing but the names given to aggregates of such sensible qualities. All physical change, then, can be reduced to the modification of these aggregates by the motion of the corpuscles. According to this program, the superiority of the mechanical philosophy comes from its capacity to explain all phenomena, starting from clear and primitive notions, without introducing any superfluous entity.[65]

But just as Descartes did not always provide explanations in terms of corpuscles, Boyle did not always provide explanations in terms of textures. His *New Experiments Physico-Mechanical Touching the Spring of the Air and its Effects* (1660) makes the claim “that there is a Spring, or Elastical power in the Air we live in,”[66] and outlines two mechanical explanations of such a spring. According to the first, the corpuscles of the air have a structure that makes them dilate; according to the second, the agitation of the subtle matter surrounding the corpuscles of the air makes them dilate.[67] Unable to adjudicate between these two explanations, he concluded

[62] (Hutchins 2015)

[63] (Boyle 1999-2000, 5:305-334) See (Alexander 1985, 62-80; Anstey 2000, 41-54; Downing 2002, 340-343: Garber, 2013; Roux 2017, 27-29).

[64] See (Alexander 1985, 78-79, 85-87; Anstey 2000, 48-50; Newman 2006, 180-189).

[65] See (Chalmers 1993; Anstey 2000; Downing 2002, 346-347).

[66] (Boyle 1999-2000, 1:165) On what follows, see (Gabbey 1982; Shapin and Schaffer 1985, 207-224; Gabbey 1990b; Henry 1990).

[67] In the *New Experiments,* the term ‘mechanical’ is not associated with explanations; its only occurrences are when Boyle mentions the “testimony of a thousand of Chymical and Mechanical Experiments,” when he speaks of “Statical

that his design was "not to assign the adequate cause of the Spring of the Air, but onely to manifest, That the Air has a Spring, and to relate some of its effects."[68] Thus, in 1660, Boyle expected from a mechanical explanation that it hypothesizes which corpuscles were the cause of a phenomenon, but he explicitly refused to assign such an explanation to the spring of the air. His controversy with Henry More led him to insist on other meanings of the word "mechanical" and to upgrade as mechanical his experiments on the spring of the air.

As he explained in a letter to Boyle, More always believed that the "mechanical way would not hold in all phenomena" and that establishing the explanatory gaps it left open would demonstrate the existence of incorporeal beings.[69] Being convinced that Descartes had given the best possible mechanical accounts of natural phenomena,[70] he held that establishing the incompleteness of Cartesian explanations amounted to demonstrating that the phenomena in question were not mechanically explicable, which in turn was to demonstrate the existence of a Spirit of Nature.[71] The thirty-third of Boyle's *New Experiments Physico-Mechanical*, according to which the suction of the exhausted air pump lifts a weight of hundred pounds, offered him yet another occasion to prove the existence of the Spirit of Nature. For Boyle, "the most plausible *Mechanical* solution" of this phenomenon was the spring of the air. If such a power existed, More argued, it would press a lump of butter with a force equivalent to a hundred pounds and squeeze the liquid out of it. But this does not occur, so the spring of the air is not a proper *explanans* and Boyle's experiment cannot be accounted for without appealing to an immaterial principle.[72]

In his *Hydrostatical discourse* (1672), Boyle repeats in reply that his intention was only to account for some phenomena by the weight and spring of the air. But while he had previously set aside mechanical explanation of these principles, he now claimed that he had *already* provided them. He notes that his accounts are "grounded upon the Laws of the Mechanicks" and that Archimedes and Stevin, the discipline's founders, did not enquire into the cause of gravity.

> Since then the assigning of the true cause of Gravity is not required in the Staticks themselves, though one of the principal and most known of the

and Mechanical Experiments," and when he notes that the "Mechanicall contrivance" of a device would not make it work without a "Chymicall liquor" (Boyle 1999-2000, 1:256, 263, 288). But Boyle explicitly presented these two explanations as "mechanical" in other places (Boyle 1999-2000, 1:150; 3:161).

[68] (Boyle 1999-2000, 1:166)

[69] (More 1659, 196-204; More 1662, 42-47; Boyle 2001, 4:231-232)

[70] (More 1659, 12; More 1671, 119, 223; Gabbey 1990b, 30-31)

[71] (More 1659, 196-204; More 1662, 42-47)

[72] (More 1662, 45-46) For this argument, see also (More 1671, 125-150, esp. 140-141; Gabbey 1990b, 22-25).

Mechanical Disciplines; Why may not other Propositions and Accounts, that suppose Gravity in the Air … be look'd on as Mechanical?[73]

Whereas Descartes referenced the laws of mechanics to *eliminate* obscure faculties, here Boyle uses them to *include* gravity, and elasticity with it, among the "mechanical affections of matter," next to motion, bigness, and shape.[74] For all that, Boyle does not go as far as including the Spirit of nature in his natural philosophy; he compares its use by More to the way in which the King of China invoked life to account for the capacity of a watch to mark the hours, while the shapes, sizes, and motions are sufficient.[75] Boyle still wants to eliminate superfluous entities, but he modifies his former notion of a mechanical explanation. It first implied reducing phenomena to textures; it now means resorting to the experimentally established properties of machines.

If Descartes could assume that his structural explanations were in principle ultimately reducible to corpuscular explanations, the gap was greater here. Boyle sought a solution to this problem in his doctrine of intermediate explanations. He distinguished between all-the-way-down explanations, "that are most satisfactory for the Understanding, wherein 'tis shewn how the effect is produc'd by the more primitive and Catholick Affection of Matter, namely bulk, shape and motion," and other explanations that are not inadmissible, even if less satisfactory, "wherein particular effects are deduced from the more obvious and familiar Qualities or states of Bodies." For example, even if the density of materials, the spring of the air, or the purgative virtue of rhubarb are not actually reduced to corpuscles in motion; that gold is denser than mercury explains why it sinks in it, the elasticity of the air explains the return to its original form of a compressed bladder, and the purgative virtue of rhubarb explains medical cures.[76] There are indeed many such explanations relying on principles like "Heat, Cold, Weight, Fluidity, Hardness, Fermentation," "Gravity, Fermentation, Springiness, Magnetism," "the Cosmographical, the Hydrostatical, the Anatomical, the Magnetical, the Chymical, and the other Causes or reasons of Phaenomena "—in a word, on "the most usefull notions we have both in Physics, Mechanicks, Chymistry, and the Medicinal Art."[77] Epicureans and Cartesians, if they refuse such principles, will contribute to the advancement of natural philosophy no more than Aristotelians.[78]

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[73] (Boyle 1999-2000, 7:148)

[74] (Boyle 1999-2000, 7:159, 183)

[75] (Boyle 1999-2000, 7:182-183)

[76] (Boyle 1999-2000, 2:21-23; Boyle 2004, 8:165r-166r, 169r-170r; 9:40v-41r) See (Laudan 1981; Chalmers 1993; Anstey 2002; Chalmers 2002; Downing 2002, 348-349; Chalmers 2010; Newman 2010; Chalmers 2011; Chalmers 2012).

[77] (Boyle 1999-2000, 2:21; Boyle 2004, 9:40v)

[78] (Boyle 2004, 8:165r-166r)

Intermediate explanations make room, beyond the requirement of intelligibility, for experimental properties. All commentators now recognize their importance, but their status with respect to the mechanical philosophy is a bone of contention. Using a contemporary demarcation between science and philosophy, Alan Chalmers presents them as a felicitous departure from a misguided mechanical philosophy, which he defines as the reduction of phenomena to geometrical corpuscles. Peter Anstey and William Newman, on the other hand, describe them as part of Boyle's mechanical philosophy, because they credit his later writings and assume his expectations with regards to the mechanical philosophy never changed.[79] Yet attention to Boyle's controversies yields the moderate conclusion that, while always maintaining a principle of parsimony, he may have had different strategies against different opponents. Against Aristotelians entities, he insisted that the mechanical philosophy reduces phenomena to underlying textures; against More's Spirit of Nature, he insisted that only experimentally established properties are admitted into the mechanical philosophy.

1.3.3 Huygens and Leibniz versus Newton: mathematical descriptions have to be completed by mechanical explanations

The last controversy on which we will focus is the debate about attraction sparked by Newton's *Principia mathematica philosophiae naturalis* (1687). If Descartes and Boyle used mechanical explanations to eliminate obscure faculties and immaterial principles, Huygens and Leibniz privileged intelligibility at the expense of parsimony in their fight against attraction. More precisely, they reproached Newton for wrongly conflating physics with mathematics, instead of completing mathematical descriptions by mechanical explanations that are intelligible. This in turn led Newton to give priority to what is experimentally established over what is intelligible, and thus to distance himself from the intelligibility requirement, or at least from the idea that mechanical explanations would be what best satisfies it.

Newton himself declared in the Preface to *Principia* that his main result consists in deriving the forces of gravity from the celestial phenomena and, reciprocally, in deriving the celestial motions from these forces. He then wished that "the same kind of reasoning from mechanical principles" would be extended to all other natural phenomena. 'Mechanical principles' does not refer here to the corpuscular principles of the mechanical philosophy, but to the mathematical science of motions and forces, for which Newton claimed the same exactness as geometry.[80] More generally, he insisted on several occasions that forces of attraction and

[79] (Anstey 2002, 164-165, 169-70; Chalmers 2002, 194-197; Chalmers 2010, 5-7; Newman 2010; Chalmers 2011, 151-152)

[80] On the meaning of 'mechanics' in the *Principia*, see (Gabbey 1992; Guicciardini 2007).

impulse were considered only from a mathematical perspective, not from a physical one.[81] Resistance to this division of labor between physics and mathematics explains the reaction of the anonymous reviewer in the *Journal des sçavans*, who lauded the exactness of the mathematical mechanics in the first two books of the *Principia*, but criticized the physics of the third book for relying on the arbitrary hypothesis of universal attraction.[82]

Similarly, the irreducibility of physics to mathematics is at the heart of Huygens's attempts to give a mechanical account for gravity. When he first heard of Newton's book, Huygens response was mixed.[83] On the one hand, he was convinced that Descartes's explanation of terrestrial gravity by a vortex of celestial matter had serious flaws,[84] and he was glad that Newton had "brushed aside" the Cartesian vortices carrying the planets around the Sun as incompatible with Kepler's laws and with the eccentric motions of the comets.[85] On the other hand, he judged that the principle of attraction was "absurd,"[86] because supposing such a quality inherent in matter departed from "mathematical or mechanical principles."[87] Where Newton, in *Principia*, equated mechanics with the mathematical science of motions and forces, Huygens demanded here that mathematical principles should go no further than what is permitted by mechanical principles that form "the true and sound philosophy."[88] Thus, even if Huygens abandoned Cartesian vortices to explain the motion of the planets around the Sun, he still used a subtle matter to explain gravity.

To "make the eye see an image of gravity," Huygens proposed an experiment. Some wax is placed in a closed jar filled with water, which is then spun, so the wax goes to the periphery. When the jar is stopped, the water goes on turning for a while, but the wax goes immediately to the center, the centrifugal force in the water inducing a centripetal motion of the wax. At this point, there is still a disanalogy with gravity—the wax follows spirals, not straight lines, to the center, and it cannot be excluded that the wax's specific gravity is sufficient to explain its behavior. Huygens thus installed small nets that made the wax follow straight lines towards the center of the jar, and he replaced the wax with a body of the same specific gravity as water.[89] Having set up an experiment that represents the most notable characteristic of terrestrial

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81 See, for example, Definition 8 and Book 1, Section 11, scholium, in (Newton 1999, 407, 588-589).

82 (De Sallo 1689, 237-238) On what follows, see (Aiton 1972; Snelders 1989; Gabbey 1992; Lunteren 2002).

83 (Huygens 1888-1950, 9:168-169, 190)

84 (Huygens 1888-1950, 21:455) For other objections, see (Huygens 1888-1950, 19:627).

85 (Huygens 1888-1950, 21:143) See also (Huygens 1888-1950, 9:368; 10:385; 19:310).

86 (Huygens 1888-1950, 9:538)

87 (Huygens 1888-1950, 21:474)

88 (Huygens 1888-1950, 21:446)

89 (Huygens 1888-1950, 21:453-454) See also (Descartes 1964-1974, 2:593-594).

gravity—its centripetal effect—in terms of a circulating fluid, Huygens examines the conditions the subtle matter and its motion must obey in order for this experiment to be transposable to the case of terrestrial gravity. A first condition is that the motion is circular in all directions. Moreover, the matter has to be sufficiently subtle to penetrate all bodies freely. Finally, the theorems on centrifugal force of the *Horologium oscillatorium* (1673) make it possible to calculate that it moves seventeen times faster than an equatorial point on the Earth.[90] Thus, not only was Huygens's intelligible explanation of gravity presented in an experiment, but the speed of the subtle matter could be calculated thanks to the laws of centrifugal force.

When Huygens rejects Newton's attraction, he puts forward the requirement of intelligibility. He claims that one should avoid "obscure and unheard principles,"[91] and find "an intelligible cause of gravity"[92] that sticks to "the true Philosophy in which one conceives the cause of all natural effects by reasons of mechanics."[93] Though Leibniz's *Tentamen de motuum coelestium causis* (1689) aims to explain the motion of the planets around the Sun, not terrestrial gravity like Huygens, it is motivated by exactly the same intelligibility requirement. His letters to Huygens underline that attraction is "an incorporeal and inexplicable virtue,"[94] though the point is still muffled in his 1693 exchange with Newton.[95]

In the 1710s, however, the confrontation became perfectly clear. Whereas Boyle kept presenting his explanations as "mechanical" and claimed that qualities whose existence could be established experimentally were thereby intelligible, Leibniz and Newton realized that a choice had to be made. They agreed on the dilemma: attraction has an existence which is experimentally established, but it is not intelligible; the subtle matter is not experimentally established, but it provides an intelligible cause of attraction. They disagreed about which choice to make. Leibniz chose the second horn: he refused to admit an "unreasonable occult quality," by which he meant saying that bodies tend towards the center of the Earth "without any mechanism, by a simple primitive quality, or by a law of God, who produces that effect without using any intelligible means."[96] Newton chose the first, and his answers to Leibniz were twofold. First, he pointed out that "primitive" qualities indispensable to mechanical explanations, such as the force of inertia, extension, duration, and mobility of bodies, would be, by Leibniz's lights,

[90] (Huygens 1888-1950, 21:454-461)

[91] (Huygens 1888-1950, 21:445)

[92] (Huygens 1888-1950, 19:631, 642; 21:451)

[93] (Huygens 1888-1950, 19:461)

[94] (Huygens, 9:523)

[95] (Newton 2004, 106-109)

[96] (Newton 2004, 112)

occult qualities.[97] However, Newton's most consistent reply was to advance an alternative definition of 'occult qualities'. They are not qualities whose cause is unknown, but whose existence is not experimentally attested. For Newton, contrary to Boyle, mechanical explanations, if they are opposed to propositions relying on experimentally established qualities, are fictions of our own devising, mere hypotheses, and vain dreams.[98]

1.4 The Evaluation of Mechanical Explanations

The debate about universal attraction is crucial to the negative evaluation of the mechanical philosophy mentioned in the first section of this chapter. While, in retrospect, we laud Descartes's or Boyle's attempts to rid natural philosophy of obscure faculties and immaterial principles, we condemn Huygens's and Leibniz's wish to complete the mathematical description of attraction with a mechanism as a retrograde demand for impossible reductions to corpuscles and their motions. There are two strategies to counter this negative evaluation. The first is to reject anachronistic judgments and show the contextual value of mechanical philosophy against various opponents; this is what was done in the third section of this chapter. The second strategy consists in forging tools for a more positive evaluation.

To do this, we must first avoid focusing on mechanical explanations that were epistemologically weak. There were without doubt mechanical explanations in chymistry, meteorology, and related disciplines, which presupposed untested correspondence between phenomenal properties and the configuration of corpuscles. Thus, as we have seen, Boyle's favorite explanation of the elasticity of the air consists in comparing its corpuscles to little springs.[99] Similarly, Gassendi explains the fall of heavy bodies by the conjunction of two external forces: the pushing force of the air from above, and the force of some magnetic corpuscles emitted by the Earth that pull bodies down as insensible ropes or hooks would do.[100] Or still, Lemery associates acidity with pointed corpuscles that open pores, divide some parts and are deflected by others, and sometimes become blunted and other times break.[101] Once we have identified the reasons why such mechanical explanations are unfounded, there is no point in agonizing about them *ad nauseam*. Rather, we have to leave them aside and examine the cognitive benefits that mechanical philosophers were entitled to expect from their explanations.

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[97] (Newton 2004, 116)

[98] (Newton 1999, 392, 795-796, 943)

[99] (Boyle 1999-2000, 1:65)

[100] (Gassendi 1658, 3:489-496)

[101] (Lemery 1675, 10, 15, 44-45, 57, 90, 108, 142, 155-157)

Second, our concept of science has to be broadened and diversified. However crucial experiments and mathematical formalization may be even today, science cannot be reduced to these two elements, which, moreover, vary from one science to another. Insofar as the negative estimation of demands for mechanical explanation is grounded in a specific model of the science *par excellence* as a physics relying on mathematical laws, it is useful to take another science as a model. One can think in particular of biology, which still places great emphasis on mechanisms.[102]

In this respect, it is to be noted that a number of early modern mechanical explanations, especially in biology, were not based on corpuscles, but on comparisons with machines, which appear as moving structures. To avoid using the neologism 'machinical', but also to comply with a suggestion of Ernan McMullin, we can call these explanations 'structural' and characterize them as those causally explaining the behaviors of complex entities by their structures, that is by the "set[s] of constituent entities or processes and the relationships between them."[103] One example we have already met—Descartes's account of the circulation of the blood, where the sequence of motions involved obviously depends on the bodily structure in which it takes place.[104] There are two reasons why such explanations are numerous in anatomy, physiology, and medicine. First, they are appropriate to account for the internal functions of animals—a machine can be broken down into parts, each of which has a certain function with respect to the whole. Second, they are appropriate to account for the functional identity and functional unity of animals—even if the material parts of a machine are changed, as long as it is able to perform its function, it is one and the same machine.

Once the cognitive advantage of structural explanations has been recognized, particularly when it comes to account for animal organisms, it should be emphasized that they were not essentially distinct from other mechanical explanations. On the one hand, since structures can be seen as combinations of corpuscles, there is a continuity between corpuscular and structural explanations. Thus, Gassendi and Boyle suggested that combinations of corpuscles form what they respectively call *semina rerum* or *molecula* and textures or primary concretions.[105] On the other hand, if, in these explanations, the explanatory burden lies on structures, they do not exclude for all that laws of nature. As we have indeed seen in the case of Huygens's explanation of gravity, the causal structure that was put in place was accommodated

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[102] See (Roux 2017; Bertoloni Meli 2019).

[103] (McMullin 1978, 139, 145-147) See also (Gabbey 1985, 11-12; Gabbey 1990a, 274-286; Gabbey 2002, 453-454).

[104] Similarly, see Perrault's account of muscle contraction (Perrault 1680, 75-777), discussed in (Des Chene 2005; Roux 2012).

[105] (Gassendi 1658, 1:282b, 472a, 335b; Boyle 1999-2000, 5:333-334)

to an experiment and to quantified laws of motion. In fact, whether in Borelli's *De motu animalium* (1680–1681), in Boyle's *A Free Enquiry into the Vulgarly Received Notion of Nature* (1686), or in Fontenelle's *Entretiens sur la pluralité des mondes* (1686), corpuscular explanations, structural explanations, and nomological explanations were expressed in the same breath. All of them were to be seen as part of the mechanical philosophy, that should be preferred, in the words of Samuel Parker, "not so much because of its so much greater certainty, but because it puts inquisitive men into a method to attain it."[106]

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[106] (Parker 1666, 45)

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