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2. From the Mechanical Philosophy
To Early Modern Mechanisms

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Early modern natural philosophers put forward the ontological program that was called "mechanical philosophy" and they gave mechanical explanations for all kinds of phenomena, such as gravity, magnetism, the colors of the rainbow, the circulation of the blood, the motion of the heart and the development of animals. For a generation of historians, the mechanical philosophy was regarded as the main alternative to Aristotelian orthodoxy during the so-called Scientific Revolution and mechanical explanations were presented as paving the way for the use of experiments and mathematics in the understanding of natural phenomena. However, the historical category of mechanical philosophy was later criticized as being too broad, while early modern mechanical explanations were condemned by more epistemologically oriented minds for being incompatible with, or at least not necessarily connected to, the use of experiments and mathematics. In the last ten years, just as the new mechanistic literature emerged in philosophy of science, there has been a reevaluation of early modern mechanical explanations in a domain that had been until then considered as peripheral to the so-called Scientific Revolution, namely the domain of biology, anatomy, physiology and medicine. Although they were neither confirmed nor predictive, some early modern explanations in these domains appear to have a cognitive value similar to the value of contemporary mechanistic explanations.

1. Establishing mechanical philosophy

Boyle is often said to have coined the term "mechanical philosophy." It would be more exact to say that he was the first to use this term to advertise the general program of explaining all natural phenomena by matter and motion alone. There were indeed some earlier uses of the term. After he read *Meteors* and *Dioptrics*, Libert Froidmont complained in a letter from 1637 that Descartes fell too often into the "coarse and somewhat bloated (*ruda & pinguiscula*)" Epicurean physics; he noted in particular that the reduction of the Aristotelian elements to small parts of various figures was "too gross and mechanical (*nimis crassa & mechanica*)." In his answer to Froidmont, Descartes allowed his philosophy to be qualified as "mechanical," but he reversed the negative connotations associated to this adjective and insisted that his physics manifested a certitude similar to the certitude of mathematics only in as much as it was mechanical. Froidmont had only to see the numerous problems that Descartes was able to solve in order to understand that there was absolutely no reason to condemn his “bloated and mechanical philosophy (*pinguiscula & mechanica philosophia*)” (Descartes, 1964-1974, vol. I, pp. 402, 406, 420–421, discussed in Roux, 1996, pp. 15–17, Gabbey, 2004, pp. 18–20 and Roux, 2004, pp. 32–34). Just a few years after Descartes’ death, Henry More dubbed him “the great Master of this Mechanicall Hypothesis” (1653, p. 44). Later on, More recommended “that admirable Master of Mechaniks *Des-Cartes*” to be taught in universities in order to make the students see the limits of mechanical explanations and to enable them to beat hollow the “pretender to Mechanick Philosophy” (1659, n.p., discussed in Gabbey, 1982, pp. 220–222). These occurrences of the term “mechanical philosophy” are interesting, but they should not be equated with the establishment of mechanical philosophy. Descartes had a positive program for reducing all natural phenomena to matter and motion alone (Descartes, 1964-1974, vol. VIII, pp. 314–323, vol. XI, p. 47, *passim*), but he was not ready to include in this program those who had other conceptions of matter and motion than his own. As for More, he did not consider mechanical philosophy as a program that would have delineated how to frame physical explanations in the years to come; for him, Descartes’ explanations were essentially incomplete, and their gaps gave evidence that some kind of immaterial substance should be introduced, whether it be God or the Spirit of Nature (1653, 42–47 and 1659, pp. 193–204, discussed in Gabbey 1990b, pp. 22–25 and 30–31).

The story is different in *Some specimens of an attempt to make chymical experiments useful to illustrate the notions of the corpuscular philosophy* that Robert Boyle wrote in the late 1650s and published in his *Certain Physiological Essays* (1661). In the Preface, Boyle insisted that, notwithstanding the differences between their philosophies, Descartes and Gassendi agreed upon two things. First, contrary to Aristotelians and to chemists, they intended to “deduc[e] all the Phenomena of Nature from Matter and Local Motion.” Second, they proposed to stand up for the defense of Christian religion. At this point, Boyle needed a term to baptize the program that both Descartes and Gassendi would have shared. He actually proposed several ones: it could be called “Corpuscular,” because it explains natural phenomena through corpuscles, “Phoenician,” because it its inventor is supposed to be the Phoenician Moschus, or, still, “Mechanical,” because it gives an account of phenomena by motion, which is “obvious and very powerfull in Mechanical Engines” (1999-2000, vol. II, p. 87, discussed in Roux 1996, pp. 18-20). This ontological program was an important program, even if it was only one of Boyle’s two programs for natural philosophy, the other one being “experimental philosophy,” that is the epistemological program to acquire and secure knowledge of nature through observations and experiments (1999-2000, vol. II, p. 14, vol. III, p. 12, *passim*; see Sargent 1994, 1995; Chalmers 1993, 2012; Gaukroger 2006, pp. 352–399; Anstey and Vanzo 2012, 2016; Anstey, 2014). Boyle was not sparing his words; to designate this ontological program, he spoke also of the “New,” the “Real” or the “Atomical” philosophy

(1999-2000, vol. XI, p. 292). But his most common terms are “the corpuscular (or corpuscularian) philosophy (or hypothesis)” and “the mechanical philosophy (or hypothesis)”, the first emphasizing the kind of entities that appear in explanations (corpuscles), the second the kind of activities that these entities are engaged in (motions).

In *The Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666), publicized by Henry Oldenburg in the *Philosophical Transactions* as “a kind of *Introduction* to the Principles of the *Mechanical Philosophy*” (1666, p. 191), Boyle identified positively the eight tenets that are constitutive of this ontological program:

1. There is only one universal matter, which is extended, divisible and impenetrable.
2. The diversity between bodies comes from various affections of matter, the main of these affections being local motion.
3. Motion divides matter into parts of various sizes and figures.
4. Between several parts of matter, there are relations of order and situation, which determine the texture of a body.
5. Parts of matter in motion make some impressions on the senses of animals,
6. The sensible qualities that are associated to these impressions are nothing but the effects of matter in motion on the senses.
7. Substantial forms are nothing but the names given to aggregates of sensible qualities,
8. Generation, alteration and corruption are nothing but the names given to transformations of matter in motion (1999-2000, vol. V, pp. 305 *sqq.*).

Referring to those that Boyle himself designated as the two founding fathers of mechanical philosophy, to wit Descartes and Gassendi, will make clear that the mechanical philosophy was large enough to include various interpretations of each of these tenets.

Regarding 1, contrary to Aristotelian matter, which is a pure power, matter is a true substance (Descartes, 1964-1974, vol. XI, p. 33; Gassendi 1658, vol. III, p. 636b). Being “universal,” matter is everywhere one and the same: it is a “homogeneous” or “uniform” substance (Descartes, 1964-1974, vol. III, pp. 211–212, vol. VIII, p. 52, vol. XI, p. 17). Its only properties are extension, divisibility and impenetrability. That bodies are extended was granted by all natural philosophers; the only question was if extension was the only essential property of matter. By mentioning “divisibility,” Boyle seems to adhere to Descartes’ view, according to which there are no atoms because any part of matter can be divided further away (1964-1974, vol. III, pp. 191, 213–214, 477, vol. VI, pp. 238-239, vol. VIII-1, pp. 51–52, 58–59). Still, Descartes’ view was that matter is *infinitely* divisible, while Boyle claimed to remain neutral with respect to this question (1999-2000, vol. VIII, pp. 103–104). In fact, since Boyle admitted that there are *minima* or *prima naturalia* that are not naturally divided, though they could be divided in thought or by God (1999-

2000, vol. V, pp. 325–326), except for the words that he uses, he subscribes to Gassendi's view, according to which there are atoms that have parts but that cannot be divided by any natural force (1658, vol. I, p. 256b). Similarly, putting on a par extension and impenetrability (that is the property that a body has of excluding any other body from its location) is truer to Gassendi than to Descartes: Gassendi presented, in addition to gravity or weight, extension and impenetrability as two equally fundamental properties (1658, vol. I, pp. 55a, 267a), while Descartes asserted that impenetrability is to be derived from extension (1964-1974, vol. V, pp. 269, 341–342, vol. XI, p. 33).

Regarding 2 and 4, because of its homogeneity and uniformity, matter is not sufficient in itself to account for the variety we see in natural phenomena. This variety comes from the different shapes, sizes and motions of parts of matter and from their relationships (Descartes, 1964-1974, vol. VIII-1, pp. 52–53, vol. XI, p. 34; Gassendi 1658, vol. I, pp. 366a–371b).

3. Here, Boyle adheres to Descartes' view, according to which motion is prior to shape and size because it is responsible for slicing matter into corpuscles of various sizes and shapes (1964-1974, vol. XI, p. 34). A related point is that, for Descartes, motion does not belong to matter in itself, while, for Gassendi, matter is not inert but active, weight being a principle of motion internal to atoms as such (1658, vol. I, pp. 276b, 335b). In that respect, Boyle goes along with Descartes: against Gassendi and the Ancient atomists, he opposes the opinion that motion is essential to matter, because it would pave the way to atheism (1999-2000, vol. V, p. 306).

Regarding 5 and 6, since there are only corpuscles in motion in the world, the various qualities that animals perceived cannot but be caused by these corpuscles in motion. While Descartes did not try to give specific names to combinations of corpuscles, Gassendi and Boyle suggested that there were intermediate levels between the lowest atomic level and the highest level, which are accessible through observations and experiments; they called these intermediate levels respectively *semina rerum* or *molecula* (Gassendi 1658, vol. I, pp. 282b, 472a, 335b) and textures or primary concretions (Boyle 1999-2000, vol. V, pp. 333–334).

Regarding 7 and 8, mechanical philosophy is an eliminative reductionism that aimed at replacing the Aristotelian ontology. Considering the variety of ways in which the previous tenets were interpreted, the rejection of Aristotelian ontology was probably the only common denominator between early modern mechanical philosophers.

As he himself acknowledged, Boyle did not create this ontological program out of nothing: in the first half of the 17th century, there had been attempts to replace the dominant Aristotelian natural philosophy with a natural philosophy formulated in terms of matter and motion alone. But, possibly because of his own "reconciling Disposition," or because of a larger Latitudinarian context, Boyle was one of the first authors to propose to put aside the differences that were important to the members of the former generation and to offer to the members of the generations to come a common program in which to inscribe their works (Garber, 2013). Thus, the resemblances between Descartes and Gassendi were brought to the forefront and their differences were pushed into the background. These were metaphysical differences that concerned God and the soul, most of which were violently expressed in the controversy that went through Descartes' *Meditationes*, Gassendi's *Fifth Objections*, Descartes' *Fifth Replies*, Gassendi's *Disquisitio metaphysica*, and finally Descartes' letter to Clerselier of 12 January 1646 (Lennon, 1993; Lolordo 2007; Osler 1994; Roux 2008). There were also differences concerning the very principles of natural philosophy, as we just noted (Lennon 1993; Roux 2000). More important for us here, there were what we perceive today as epistemological differences between types of explanations (Roux, 2009, 2012). Consider for example bodies that fall on the Earth. This had to be explained, because gravity or attraction were considered as mere words, action at a distance being proscribed in favor of action by contact. According to Gassendi, the fall of heavy bodies is caused by the conjunction of two external forces, on one hand the pushing force of the air from above, on the other the force of some magnetic corpuscles emitted by the Earth that pull bodies down to the earth as small insensible ropes or hooks would do (1658, vol. III, pp. 489-496). According to Descartes, the fall of heavy bodies follows from the impossibility of the void and from his third law of nature, according to which every body, when moving circularly, tends to recede from the center of its motion, a tendency which is greater for swifter and smaller bodies. Void being impossible, the smaller and swifter bodies would not recede from the center if the bigger and slower bodies did not approach the center, which means that these bigger and slower bodies go down (1964-1974, vol. VIII, pp. 213–217; the explanation is slightly different in *Le Monde* (vol. XI, pp. 72–80), but its kingpin is the same law of nature and the impossibility of the void). Let us call Gassendi's explanation "corpuscular," in so far as the burden of explanation lies on the properties of insensible magnetic corpuscles, and Descartes' explanation "nomological," because the burden of his explanation lies on a law of nature. The distinction between corpuscular and nomological explanations does not exhaust the different types of mechanical explanations though. There were also explanations that consisted in exhibiting the causal interactions of parts of more or less complex structures. This is the type of explanation that was put in place when animals were compared with machines that can be decomposed in parts that act on each other. For example, Perrault suggests that the influx of animal spirits into a muscle causes its release, which itself causes the contraction of the antagonistic muscle, just as the release of the guy supporting a mast causes the slackening of the opposed guy (Perrault, 1680, pp. 75–77, discussed in Des Chene 2005; Roux 2012). Considering the importance that comparison with machines had for this third type of explanation, it could be called "machinical." In order to avoid neologisms, but also to comply with the distinction proposed by Ernan McMullin (1978, discussed below), let us call these "structural" explanations.

Partly because of Boyle's position at the Royal Society and partly because the ontological program of explaining natural phenomena in terms of matter and motion alone was at this time already well admitted by a number of natural philosophers, the terms "corpuscular philosophy" and "mechanical philosophy" were successful, but not always with the same connotations. Among the members of the newly founded Royal Society, the adjectives "mechanical" and "experimental" were paired together, as if each of them contributed to make the meaning of the other more precise. Henry Power presented himself as an "experimental and mechanical philosopher" (1664, p. 193), Robert Hooke contrasted "the *real*, the *mechanical*, the *experimental Philosophy*" and "the Philosophy of discourse and disputations" (1665, Sig.a2r), Samuel Parker explained that he preferred "the Mechanical and Experimental Philosophy" to the Aristotelian philosophy (1666, p. 45). In contrast, on the Continent, even those who thought that everything occurs mechanically did not often use the term "mechanical philosophy"; when they did, it referred to the demand that physical explanations are formulated in intelligible terms and connected to the mathematical sciences. It was only by reference to Boyle and the Royal Society that in this period the young Leibniz happened to speak of "corpuscularians" and of "corpuscular philosophy" (1923–, vol. VI-1, pp. 489–490, VI-2, pp. 325, 327), a term that he used at least once as equivalent with "mechanical philosophy" (1923, VI-2, p. 325). Still, he already called "mechanical" what does not rely on the supposition of fictitious entities, but on clear and simple terms (1923–, vol. II-1, pp. 266, 284, 287, 372, 379, 393). From the end of the 1670s onward, Leibniz continued to occasionally use "corpuscular philosophy" (1923–, vol. II-2, pp. 396, 845, VI-4, p. 477), but the more frequent terms from his pen were "mechanical philosophy" and related words like "mechanism," that he used in association with laws and mathematics (1923–, vol. II-2, p. 172, VI-4, pp. 485, 1559, 1566, 2009, 2118, 2342). The association of the mechanical with what is clear and intelligible, if not with mathematics, is also pregnant in the eulogies that Bernard Le Bovier de Fontenelle wrote as secretary of the *Académie des sciences*. Speaking of a chemist, he rejoiced that "the sound philosophy… undertook to reduce this mysterious chemistry to the simple corpuscular mechanics" and he defined the corpuscular philosophy as "the one where only clear ideas are admitted, that is figures and motions" (1740, vol. II, pp. 444, 250, 322).

Thus, because of the variety of these connotations, "mechanical philosophy" changed from a term for an already large ontological program into a kind of a broad umbrella term covering several programs associated with the erosion of Aristotelian natural philosophy and with the development of the new sciences (Roux, 1996). The first historians who promoted mechanical philosophy as a key-component of the Scientific Revolution took over this broad umbrella. In her influential paper from 1952, Marie Boas identified, among many others, Descartes, Boyle and Newton as the three main early modern mechanical philosophers who were able to "put atom to work" (1952, p. 540). She suggested a progression from each to the next one: Descartes would have offered a theory of matter accounting for many unexplained physical properties, Boyle would have expanded it thanks to his brilliant experiments, Newton would have put the emphasis on the mathematized law of attraction and, if he "inclined towards the non-mechanical one for want of experimental evidence," "he would have preferred a mechanical explanation" (1952, p. 519). For her, the early modern mechanical philosophy in its full form consisted in adapting the ancient atomism to the new science of mechanics, characterized by the use of experiments and mathematics (1952, pp. 414, 426, 520–521). Another example of these first promoters of the historiographical category of the mechanical philosophy is Eduard Jan Dijksterhuis. According to the opening words of his monumental *Mechanization of the world picture*, first published in Dutch in 1950 and then translated in several European languages, the emergence of "the conception of the world usually called mechanical or mechanistic" had more profound and far-reaching effects than any other conception of the world (1961, p. 3). In a word, these historians described the ontology of matter and motion as necessarily implying a certain access to nature (that is, through observations and experiments) as well as a certain development of knowledge (thanks to mathematics). For them, the mechanical philosophy was thus essentially linked to the two most eminent characteristics of the Scientific Revolution and, beyond that, of modern science, that is, experimentation and mathematization.

2. Challenging mechanical philosophy

Still, questions about the delineation of mechanical philosophy emerged and the cluster of associated programs began to come apart. Of course, some of these programs were *sometimes*, in *some* places and in *some* respects associated, but a natural philosopher engaged in one of them did not necessarily engage in all the others. Already in *The Mechanization of the world picture*, Dijksterhuis made a distinction between mechanics as the science of motion and mechanics as the theory of machines; in his conclusion, he pointed out that what led to the mechanization of the world picture was not the theory of machines, but rather a science of motion that should be characterized as a "mathematism" rather than as a "mechanism" (1961, pp. 4, 498). In his short textbook, *The Construction of Modern Science, Mechanisms and Mechanics,* which has achieved an enduring success since its first publication in 1971, Richard Westfall dissociated two traditions that had been conflated by Boas: the mechanical philosophy, which "conceived of nature as a huge machine and sought to explain the hidden mechanisms behind phenomena" and the Platonic-Pythagorean tradition, which developed in the mathematized science of mechanics. According to him, the tension between these two conflicting traditions was resolved only with Newton, which is to grant some significance to mechanical philosophy (1977, pp. 1, 36, 42, 120). But when Westfall comes to the point of explaining what exactly the mechanical philosophy brought to sciences such as optics, chemistry and biology, Westfall presents it as a language, an idiom, a facade, a robe or even a puppet regime (1977, pp. 41–42, 50, 56, 73, 77, 94, 104). This amounts to saying that mechanical philosophy was something external to the sciences. Introducing Gassendi, Westfall went as far as speaking of "the occupational vice of mechanical philosophers, the imaginary construction of invisible mechanisms to account for phenomena" (1977, p. 41, see also pp. 1, 56).

It was only however in the 1990s that the category of mechanical philosophy was systematically debunked from a historical point of view. It was pointed out that to regard the mechanical philosophy as the principal alternative to Aristotelian orthodoxy was a significant oversimplification of the historical situation. Learned studies emphasized that the great authors owed more to the scholastics than they had been willing to admit, and for the lesser authors, that they had at times taken such complex positions that the division between the mechanical and the non-mechanical philosophies became impossible to draw in practice, all the more so given that the Aristotelian doctrine of *minima naturalia* helped the development of some corpuscularianisms (Leijenhorst, 2002; Lüthy, 1997, 2001a, 2001b; Murdoch 2001). It had been known for twenty years that various magical and hermetic philosophies were available at the time (Bonelli and Shea, 1975; Westman and McGuire, 1976), but only in the 1990s were the alchemical roots and active principles in some early modern corpuscularianisms recognized (Clericuzio, 1990, 2000; Henry, 1986, 1989; Newman 1994, 2001, 2006; Principe, 1998). In addition, it was pointed out that the first generation of the so-called mechanical philosophers did not identify themselves as belonging to a common program, but rather as competitors in the search for a new philosophy intended to replace the philosophy of the schools (Gabbey, 2004; Garber, 2013).

In short, the category of mechanical philosophy came to be thought of as lacking any real historical significance, except when applied to authors like Boyle who explicitly defined it. It was particularly feared that it represented a bad partition of seventeenth-century natural philosophies, ill suited for drawing out their inexhaustible richness and their fast transformation. While I concur with the historical criticisms that have been addressed to the obviously too broad category of mechanical philosophy, in this chapter I want to focus on the epistemological grounds that have been used to scrutinize mechanical explanations. For the sake of clarity, I will distinguish a *de jure* evaluation that bears on mechanical explanations in general from a *de facto* evaluation that affects some mechanical explanations only.

The *de jure* evaluation was based on a normative notion of science, according to which something deserves to be positively evaluated if and only if it complies with certain well-established standards, that is, in the case of science, the use of mathematics and the recourse to experimental proofs. For example, Gaston Bachelard famously said that Descartes' physics "should be left in its historical solitude," because it would be a physics "where objects are not measured, a physics without equations, a geometrical representation without scale, without mathematics" (1951, p. 35). Similarly, with regards to the recourse to experimental proofs, Alan Chalmers argued that Boyle's successes were "achieved in spite, rather than because, of his allegiance to mechanical philosophy" (1993, p. 541; and again, 2012). Contrary to the first historians who promoted the category of mechanical philosophy, Bachelard and Chalmers described the link between mechanical explanations on the one hand and mathematization or experimentation on the other hand as a kind of union against nature: as such, mechanical explanations would stay outside of proper science, they would even constitute an obstacle to the achievement of scientific norms. If mechanical philosophy was saved, it was not for its explanatory successes, but only because it functioned as a unifying discourse that legitimized scientific practices (Gaukroger, 2006, pp. 253–255, 260, 397–406).

There were also *de facto* criticisms addressed to mechanical explanations. In this case, the objector did not say that they were flawed in principle and that they were doomed to be false, but in a more descriptive way, noted that some of them happened to be vacuous. Ernan McMullin characterized structural explanations as obtaining when the properties or behavior of a complex entity are explained by the structure of that entity, that is by "a set of constituent entities or processes and to the relationships between them." Moreover, he noted that, by contrast with nomological explanations, such explanations are causal, the *explanans* being a structure that causes the *explanandum* (McMullin, 1978, pp. 139, 145-147). Relying on the notion of structural explanation, Alan Gabbey proposed to consider mechanical explanations as a kind of structural explanations (This is obviously a restriction; if mechanical explanations are defined as those that are formulated in terms of matter and motion alone, they include corpuscular and nomological explanations, as was noted in the first part of this paper.) This led him to formulate a nuanced judgment on mechanical explanations. Some of them were indeed successful when the phenomenon at stake was represented by a working model which instantiated a physical law or property or still a more familiar reality (the distinction between the two cases is presented as one of degree in Gabbey 2001, p. 454). It may happen that the working model at stake leads to a falsification of the explanation – for example, Newton falsified the explanation that Descartes proposed of the motion of the planets around the Sun by comparison with the motion of small bodies in a basin of swirling water – but this, being only the usual game of science, does not mean that the explanation was flawed in principle (Gabbey 1985, pp. 11-12; 1990a, pp. 274-286; 2001, p. 453). But, continues Gabbey, not all mechanical explanations were successful in this sense: most notably, the explanations that pretended to account for sensations in terms of "adequate" or "appropriate" corpuscles and motions failed because they turned out to be tautological or circular. For example, Walter Charleton writes that the "Odours… can never be explained, but by assuming a certain

Commensuration, or Correspondency, betwixt the Particles amassing the Odour, and the Contexture of the Olfactory Nerves" (Charleton, pp. 236–237, quoted and discussed in Gabbey 1985, pp. 12-14, 1990a, pp. 278-282, Gabbey 2001, pp. 461–462; on the "incommensurability" between a sensation and its mechanical explanation, see Meyerson 1951, pp. 334-337). When they proposed such explanations, mechanical philosophers did not progress one step beyond Molière's doctor. When this doctor said that opium causes sleep because it has a dormitive virtue, he referred to an empirical property, since opium has indeed the property to make one's sleep, but redoubles the *explanandum* – this empirical property – by a vacuous *explanans* – a dormitive virtue; asserting, as Cartesians did, that opium has a corpuscular structure that is appropriate to make one sleep is no better, because the *explanans* – the "appropriate" corpuscular structure of opium – only redoubles the *explanandum* – the fact that one sleeps when we swallow opium (Gabbey 2001, p. 462). As to the reason why mechanical philosophers proposed such tautological explanations, it was because of their situation of competition with the Aristotelians: Aristotle's worldview, to which they intended to offer a plausible alternative, continued to shape their agenda (Gabbey 1985, pp. 13-14, 1990a, p. 279; see also Clarke, 1989, p. 189).

Although Gabbey had a nuanced judgment concerning the value of mechanical explanations, his papers were perceived as reinforcing the *de jure* criticisms of mechanical explanations. When these were studied at all, they were not considered as an epistemologically legitimate practice, but as an outdated phenomenon to be studied from a contextualized point of view – much like the remnants of a lost civilization, the meaning of which we cannot perceive. This contextualized treatment of mechanical explanations was all the more striking given that, at about the same time, historians of science claimed that practices that had been until that point neglected and even rejected as irrational, for example alchemical practices, had a rationality of their own (Principe 1998; Newman 2001, 2006). In the last ten years however, while the new mechanism literature emerged in philosophy of science, there was a reevaluation of early modern mechanical explanations in a domain that had been until then considered as peripheral to, namely the domain of biology and biology-related disciplines. Comparing early modern explanations with the new mechanism literature will bring to light a number of points of epistemological interest.

3. Reevaluating mechanical explanations

As we have seen, the *de jure* negative evaluation of mechanical explanations was grounded on a specific picture of science, according to which the science *par excellence* would be a physics relying on mathematical laws; not surprisingly, when McMullin and Gabbey began to evaluate them more positively, it was through the notion of structural explanation, which was introduced by contrast to the notion of nomological explanation. Similarly, if one sets aside some forerunners

(Haugeland, 1978; Salmon, 1984; Glennan, 1996 and 2002), the mechanistic literature of the 2000s began with the observation that the standard philosophy of science, being modeled after parts of physics that rely on mathematized laws, did not say a word about mechanisms, notwithstanding the fact that the use of mechanisms is more than frequent in contemporary biology and biology-related disciplines (Machamer, Darden and Craver, 2000, pp. 7–8, 23; Bechtel and Abrahamsen, 2005, pp. 422–423; Bechtel and Richardson, 2010, pp. xvii-xviii, Bechtel, 2011, pp. 533–534, 537, 539). Such a similarity suggests that we draw a parallel between contemporary mechanistic explanations and early modern mechanical explanations.

This parallel is all the more justified, given that the word "mechanism" itself was a neologism first coined by the very members of the Royal Society who, in the 1660s in England, began to use the term "mechanical philosophy." In the *Immortality of the Soul*, More opposes Descartes' assertion that we may blink without the intermeddling of the soul, "for if one… can keep himself from the fear of any hurt… he may easily abstain from winking: But if fear surprise him, the Soule is to be entitled to the action, and not the meer Mechanisme of the Body" (1659, p. 103). Similarly, Power claimed that the microscope would allow "the illustrious wits of the Atomical and Corpuscularian Philosophers " to see "the curious Mechanism and organical Contrivance of those Minute Animals, with their distinct parts, colour, figure and motion" (1664, p. 5), the *Philosophical transactions* reported that Thomas Willis' *Pharmaceutice rationalis* exposes the "mechanism and power" by which "medicaments do their works," the "mechanical way" being contrasted to "specifique vertues" (1673, pp. 6166–6167) and Nehemiah Grew presented as a "mechanism" a membrane that functions as a bow (1682, p. 13). In his *Micrographia*, Hooke used often the word "mechanism" in association with "curious," "stupendious" and "excellent" to designate an exquisitely framed structure or contrivance which is apt to accomplish certain functions (1665, pp. 91, 95, 102, 134, 152, 154, 165, 170–171, 173). There are differences between the philosophical backgrounds of More, Power, Willis and Hooke, but under their pen, "mechanism" referred, most notably with regards to the anatomy and physiology of plants, animals and human beings, to a delicate material structure that accomplishes a function without the intervention of any internal vital or spiritual principle (Bertoloni Meli, 2011, pp. 12–16, to whom I owe some of the preceding occurrences). Here again Leibniz can be considered as a go-between in as much as he introduced the word on the continent (1923–, vol. II-1, p. 713, II-3, pp. 452, 713). However, in French "la mécanique" was for a long time preferred to "le mécanisme" for designating, especially in the case of animals, a structure that accomplishes a function (Fontenelle 1740, vol. I pp. 175, 249, vol. II, pp. xii, xxi). It was only in Stahl's *Disquisitio de mechanismi et organismi diversitate* and in his ensuing controversy with Leibniz that mechanism began to be opposed to organism (1737).

Before drawing a parallel between early modern mechanical explanations and contemporary mechanistic explanations, a few caveats are necessary. First, it should not cover up the differing intellectual contexts in which the two enterprises were formulated (Theurer, 2013, pp. 913–914). The mechanical philosophy was a reaction against Aristotelian natural philosophy and various Renaissance natural philosophies drawing a sharp distinction between artificial and natural beings; against them, the mechanical philosophy insisted on the homogeneity of nature and on the universality of its laws. The contemporary mechanistic literature is directed against the 1960s philosophers of science who prioritized physics over the other sciences and consequently put the stress on a nomological account of the sciences; against them, this mechanistic literature insisted that one should take into account mechanisms to capture the specificity of biology with regard to the other sciences.

Second, although the contemporary mechanistic literature includes sometimes some references to the early modern period (Glennan, 1996, pp. 50–51; Craver and Darden, 2005, pp. 237–239; Nicholson, 2012; Theurer, 2013) and, conversely, although some historians of early modern natural philosophy were involved in this literature (Des Chene 2005; Hutchins, 2015), the development of a mechanistic literature in the philosophy of science and the reevaluation of early modern mechanical explanations in the history of science were largely independent.

Third, it is out of question to dwell on the details of the proliferating contemporary mechanistic literature. It is all the more out of question given that this literature is not completely unanimous on what is a mechanism, since it includes two distinct traditions, the first one focusing on mechanical systems, the second one focusing on causal processes (for other attempts of disambiguation of the notion of mechanism, see Glennan, 2002; Nicholson, 2012; Theurer, 2013). To overcome this problem, I will focus primarily on an especially relevant paper of the first tradition (Bechtel and Abrahamsen, 2005).

Bechtel and Abrahamsen give the following definition of mechanism:

“A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organization. Moreover:

- The component parts of the mechanism are those that figure in producing a phenomenon of interest.
- Each component operation involves at least one component part.
- Operations can be organized simply by temporal sequence.
- Mechanisms may involve multiple levels of organization” (2005, p. 423).

It is a definition that immediately makes sense if one thinks about mechanical devices like clocks and automata that were constructed from the medieval period to early modern times. It is indeed by reference to machines that Bechtel and Richardson first introduced the notion of mechanistic explanation, albeit noting that this notion was extended when the technological context evolved (Bechtel and Richardson, 2010, pp. 17–18; Bechtel 2011, pp. 535–536; Craver and Darden, 2005, p. 234; but note that Craver and Darden 2013, pp. 15–16, suggest to we should distinguish machines and mechanisms). Thus it is important to ask the question of what stays of the initial inspiration when the notion is extended. While Machamer, Darden and Craver answer this question by associating mechanism to entities and activities in general (2000, pp. 3–4), Bechtel and Abrahamsen say, not incompatibly but more precisely, that a mechanism is a system composed of parts that interact to perform functions. Discovering a mechanism is to bring to light various relations thanks to different cognitive strategies. First, a strategy of decomposition that reveals the mereological relation between the parts and the whole structure, a relation which is relative, since something which is a part with respect to the whole structure can be considered as a whole with respect to its component parts. Second, there is a strategy of localization, since these parts are arranged in specific spatial relationships in order to interact, while the operations that they perform follow successive temporal orderings. Finally, there are relations of causality between parts and operations as well as between structure and function: parts produce operations, while the whole structure performs a function. Discovering a mechanism implies decomposing a structure in parts, identifying their localizations and interactions, describing them as causes of the phenomenon at stake.

Since mechanisms are said to be composed of localized parts that perform operations in time, it is only natural to represent them in diagrams that make use of spatial relations to convey information both on the situation of parts in space and on the succession of operations in time. Bechtel and Abrahamsen notice that, considering what our cognitive faculties are, the information that is to be found in diagrams representing mechanisms could not be conveyed verbally, or at least could not be conveyed so easily, inference procedures being different whether one starts with a proposition or with a diagram. Moreover, they add that, to reason about diagrams, the cognitive agent probably refers to former perceptions to mentally animate the diagram and imagine how a part may act on another part. When looking at the different parts of the diagram and following the temporal order, usually indicated by arrows, she will be able to simulate the sequences of operations -- provided of course that the mechanism at stake is simple enough (Bechtel and Abrahamsen, 2005, pp. 426–431; Bechtel and Richardson, 2010, xix; Chapter 18, this volume; Machamer, Darden and Craver, 2000, pp. 8–11, observe that mechanisms are represented in diagrams as well, but they cannot easily justify it because of their larger notion of mechanism).

When confronted with such a notion of mechanism, the historian of early modern science could react negatively and say that, when the new mechanists refer to the early modern period, they do it crudely. But the contemporary notion of mechanism and its correlation with diagrams may nonetheless illuminate the epistemic strategies at stake in some early modern mechanical explanations. Considering that the contemporary notion of mechanism appeared in the philosophy of biology, the obvious move is to turn to biological writings; and considering that Descartes played the role of the mechanical philosopher *par excellence*, it is natural to focus in particular on Descartes' biological writings. While the mechanical philosophy has been for a long time censured as irrelevant to biology (Westfall, 1977, pp. 94–104), it is indeed in this domain that historians of early modern thought began to see mechanical explanations with a new eye.

Spirits and Clocks, the book that Dennis Des Chene devoted to Descartes' biology, was a starting point in this respect. Des Chene focused on machines as they were represented in the so-called Theaters of machines, huge books displaying pictures of machines that the early modern engineers boasted they were able to build. It has been often noted since Jurgis Baltrusaïtis and Geneviève Rodis-Lewis that Descartes may have referred to these books, more especially to Salomon de Caus' *Des raisons des forces mouvantes*, when, at the beginning of his treatise *On Man*, he alluded to the marvelous machines that were found in the Gardens of the Greats (de Caus 1615; Descartes, 1964-1974, vol. XI, pp. 130–132; Baltrusaitis 1955; Rodis-Lewis 1956). And it has been consequently argued that he may have been inspired by these books to think that animals are only more complex machines than those machines that we construct.

Des Chene did much more than pick up some comparisons between animal bodies and machines: he showed that Descartes explained and represented organisms as the engineers explained and represented machines in Theaters of machines. De Caus and other engineers considered machines as spatial structures that can be decomposed into parts, each part producing an operation and all the operations being coordinated to perform a function. According to Des Chene, Descartes explained the human body in the very same way: he isolated parts (the heart, the circulatory system, the lungs), analyzed the effect produced by operations of a localized part (the heart) on the neighboring parts (the circulatory system and the lungs), and explained the functions that this succession of operations composes for the organism as a whole (circulation of the blood, respiration). Des Chene insisted also that it is essential for the machines displayed in these Theaters to be visible and to exhibit through pictures how their component mechanisms function. Likewise, Descartes' biological treatises not only described with words the sequences of operations that occur in human bodies, but made use of pictures following the same pictorial conventions as De Caus (2001, pp. 71–89). One cannot but think that De Caus and Descartes bring into play a notion of mechanism and a use of pictures that is similar to what Bechtel and Abrahamsen highlighted.

To push this further, considering that the new mechanist program appeared because the nomological and reductionist account of the sciences was inadequate in the case of biology, it can be asked what Descartes makes of laws and corpuscular reduction. Des Chene noted that Descartes' anatomical descriptions in terms of mechanisms were independent from any quantitative assessment of forces and motions (2001, pp. 83–84), but he maintained that, in principle, the reduction to simpler mechanisms should end up in descriptions formulated in terms of laws applied to extended things (2001, pp. 71–72, 154). In a recent paper, Barnaby Hutchins argued further that the reductionist ontology of the mechanical philosophy does not show up when Descartes analyses the operations of the human body; systems of mechanisms would be the only entities at play. Hutchins' general argument is that, if ontological commitments do not intervene in practice when a phenomenon is explained, it is as if they did not exist. He has a more specific argument: the explanation of the beating of the heart in the *Description of the Human Body* would be both systemic and non-reductionist. Systemic, because the explanation of the beating of the heart calls for the explanation of other associated functions (circulation of the blood and respiration), which themselves involve explanations of other bodily functions still (nutrition and assimilation). Non-reductionist, because, in the explanation of the beating of the heart, Descartes has recourse not only to corpuscles, but also to higher level entities (flesh, pores, fibers) and higher level operations (the lengthening of the heart). The lengthening of the heart is especially important: Descartes hypothesizing that it is because of this lengthening that some corpuscles of blood are expulsed, he does not reduce the higher level to the lower level, but on the contrary, makes the higher level intervene on the lower level (Hutchins, 2015).

The new literature on mechanisms and the history of early modern thought converge also in the case of diagrams. As we have seen, Bechtel and Abrahamsen insist that there is an affinity between mechanisms and diagrams that helps us understand what would be difficult to capture in verbal propositions alone, and Des Chene showed that the same pictorial conventions were implemented by De Caus for representing machines and by Descartes for representing organs. More generally, the numerous pictures that are to be found in Descartes' writings have recently been taken more seriously than before. Christoph Lüthy was one of the first scholars to recognize Descartes' innovation when he introduced pictures in books of natural philosophy, given that there were none in scholastic textbooks. However, he judged severely their function; according to him, Descartes used pictures to bridge the gap between logical deduction and rhetorical persuasion, or between his general program of natural philosophy and his particular explanations: they appeared when logical demonstrations failed (Lüthy 2006, pp. 103, 110–111).

Although Lüthy is correct that a picture does not make a demonstration, it is still worth following the logic of the pictures and understanding their cognitive function. Not only were *Essais* densely illustrated, but Descartes took great care of their pictures. He was a poor painter himself, but he followed the advice of his friend Constantyn Huygens who favored woodcuts over copperplates and preferred to place each picture in front of the corresponding text. Huygens recommended an engraver who was "rather a philosopher" and had "the understanding as quick as the chisel" and the choice fell on Franz Schooten the Younger (Descartes 1964-1974, vol. I, pp. 589, 607, 614).

[INSERT FIGURE 2.1 around here]

Huygens anticipated that, among the pictures of the *Essays*, Figure 2.1, taken from *Meteors,* would be the most difficult to draw (Descartes 1964-1974, vol. I, pp. 607, 614, discussed in Zittel, 2009, pp. 209–213). The first difficulty was probably that the picture had to convey the idea that there are corpuscles of water that have an elongated figure, although nobody has ever seen them. The trick of this picture is to include realistic elements, like the big rock on the right side or the cloud above it, that are so to speak able to transfer by contiguity some of their reality to the invisible corpuscles that they stand alongside. The second difficulty was that the idea of a transformative motion should be conveyed through a static picture, since Descartes thought corpuscles of water are progressively transformed into vapors, and vapors into clouds. The reader is invited to see this transformation that happens in time with the help of the letters that guide her gaze from the water corpuscles above (A) to the vapors in which these corpuscles occupy more space because they rotate on themselves (B), and finally to different species of clouds that move at the top of the pictures (C, D, E, F, G). It goes without saying that the existence of such corpuscles was never experimentally confirmed. Still, such a picture functions like a diagram that has the cognitive function of helping the reader to see nature as composed of corpuscles that are transformed by motion.

The pictures of the posthumously published treatise *On Man* (discussed in Wilkin 2003; Des Chene, 2001, pp. 74, 84–86; Zittel, 2009, pp. 306–346; Zittel, 2011) will help us to make a further point. Because Descartes left only two illustrations while his treatise continuously referred to pictures, his executor Claude Clerselier began to look for an engraver in 1657, then in 1659 launched a "call for pictures," that happened to stay open for almost five years until he received at last proposals from both Louis de La Forge and Gérard von Gutschoven (Clerselier, 1659 and 1664, in Descartes 1964-1974, vol. V, p. 764, vol. XI, pp. xiii-xvii). In between Frans Schuyl had published in 1662 a Latin translation of the treatise, with other pictures still. Schuyl's copperplates were much more detailed, realist and expressive than the diagrammatic woodcuts by La Forge and Gutschoven that were published in Clerselier's edition.

[INSERT FIGURE 2.2 – 2.5 around here]

Figure 2.2 gathers two pictures from Clerselier's edition representing the brain while awake and while asleep, the corresponding picture from Schuyl's edition being Figure 2.3. Or again, compare the representation of the pineal gland by Gutschoven (Figure 2.4) with its representation as a small organ in the middle of the brain by Schuyl (Figure 2.5), where, as Wilkins

(2003) observed, the realism went so far as representing the pineal gland on an independent bit of paper that can be moved by the reader. Although Claus Zittel has recently contested the pre-eminence given by all editors and commentators to Clerselier's pictures over Schuyl's pictures (2009, pp. 306–346; 2011), one does not need to decide who to support to understand that two conceptions of pictures were at stake. Clerselier, who published his edition two years after Schuyl's edition and was probably embarrassed by being so late, justified his own mode of representation. He could not but recognize that, as far as the engraving and the printing are concerned, Schuyl's pictures were better than those of La Forge and Gutshoven, but he added that they were nevertheless not so good to make things intelligible. "One should not be astonished if these figures [of Clerselier's edition] bear no resemblance to nature, because the purpose was not to make a book of anatomy…, but only to explain through these figures what M. Descartes advanced in his book, where he speaks more often of things that are not to be sensed, but that had to be rendered sensible in order to be more intelligible. But there is nothing more easy than to put them back in nature and to conceive them as they are, after having considered them other than as they are" (Clerselier, 1664; this passage is not reproduced in Descartes 1964-1974, vol. XI). Thus, while Schuyl had recourse to the conventions used in anatomy books because he considered that Descartes' explanations of animal functions would be best conveyed if the reader was first persuaded that the pictures were conform to nature, Clerselier ended up defending more schematic diagrams because he thought that one should first make Descartes' explanations intelligible, which required depicting parts and operations that are unseen. While Schuyl favored empirical adequacy, Clerselier preferred intelligibility, which he equated to visibility.

4. Conclusion

When they turn to history, some new mechanists suggest that mechanistic thinking began in the 17th century with a "restrictive ontology" and an "austere worldview" and that this view was progressively diversified and enriched (Machamer, Craver and Darden, 2000, p. 15; Craver and Darden, 2005, p. 234; Craver and Darden 2013, pp. 4–5). As it was shown, the mechanical ontology was probably more diversified in the early modern period than usually thought. But the most important lesson to draw from this chapter is that this ontology should be distinguished from the search for mechanical explanations (Des Chene, 2001, p. 14 and Des Chene, 2005, p. 246, put forwards a similar distinction between mechanism as a doctrine and mechanism as a method). The mechanical ontology was crucial to the early modern sciences because it preliminarily excluded Aristotelian and Renaissance doctrines that seemed to be incompatible with decomposition and localization. But, when the matter at hand was the explanation of specific phenomena, even Descartes the arch-mechanist made the search for particular mechanisms the primary focus; and, after him, natural philosophers or physicians did not hesitate to search for mechanisms without being committed to a mechanical ontology (Des Chene, 2005; Bertoloni Meli, 2011). In that respect, focusing on specific mechanical explanations while drawing inspiration from the new mechanistic literature is probably a more fruitful perspective on the early modern period than trying to spell out the inexhaustible varieties of the mechanical philosophy.

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