Chapter 1

Framing Mechanisms

I wish to set out my investigation with some preliminary reflections on the meaning and usage of the notion of mechanism in the early modern period. Philosophical concerns related to the notion of mechanism present many conceptual problems in their own right, though addressing the topic historically adds several specific issues to do with the changing meaning and context of usage of the term and its place in the constellation of related notions and concepts current at a time. My concern in this chapter is with how we are to talk about mechanisms, machines, and the mechanical philosophy more broadly in a historically meaningful way, one that is sensitive to these changing horizons. Of course, in no way do my reflections cover the wealth of themes and debates emerging from the historical sources. However, I hope that they could be applied to larger domains and that others may find them helpful in their own investigations.

I start from what I call the problem of labeling; namely, the study of how the term *mechanism* and its cognates can be used in historical narratives. I consider three strategies involving increasing nuance and sophistication: the first seeks to define the term accurately once and for all, providing normative conceptual clarity. This may be helpful in some respects; since meanings and contexts were in a state of flux, however, it may be helpful to adopt a more historically sensitive approach, involving not only the notion of mechanism in isolation, but also what we could call its contrast class, which shifted over time. A "mechanism versus nonmechanism" approach, too, however, while helpful in some regards, may work as a straitjacket, because over time our subjects held a range of views that is not best captured by simple dichotomies. Hence it may be appropriate to move away from a dichotomous approach and to consider both a broader spectrum of philosophical positions and a broader set of terms or notions, such as organism, for example.

In order to provide a more concrete and especially rich historical example, I review the positions Galen of Pergamon held at different times in his life on a number of issues to do with the soul and its faculties, as well as the fundamental differences between art and nature, *technē* and *physis*. At first the move to Galen in an essay focusing on the early modern period may seem surprising. However, Galen was a prolific and profound investigator both in anatomy and philosophy and is a valuable source for our reflections; moreover, his works circulated widely and were the focus of extensive debates throughout our period.

The last section identifies a number of tensions in the mechanistic program, notably between definitions and statements in principle versus practice and concrete accomplishments; between different levels of mechanistic explanations, whether limited to macroscopic dimensions or aiming at microscopic ones; in relation to shifting understanding of the term; and between imperfect human machines versus infinitely more complex and perfect divine ones. These tensions reinforce the move away from a simple dichotomous approach and point to the need for taking into account a wider spectrum of theoretical perspectives, paying attention to actors' categories and practices.

The Problem of Labeling

Several philosophers of science have sought to provide a conceptually adequate definition of the term *mechanism*, one addressing systematic concerns and capturing at the same time scientific practice. In their classic paper, Machamer, Darden, and Craver have argued: "What counts as a mechanism in science has developed over time and presumably will continue to do so." Their starting point is Galileo's reliance on the Archimedean tradition and simple machines, leading to "the mechanical philosophy." In later centuries chemical and electrical phenomena were added to the mix: "What counts as acceptable types of entities, activities, and mechanisms change with time," and the trend continues even today.[1]

The problem with some philosophers seeking to project a timeless definition onto the past is that not only the sciences and available machines but also meanings and practices shift in subtle ways in relation to broader changes in philosophical perspectives and worldviews. Over time, all such transformations can result in dramatic differences: today explanations relying on mechanism, especially those found in the life sciences, are often contrasted with lawlike explanations, which are more commonly analyzed in the philosophy of physics. In the early modern period, however, this was not the case. While most scientists today would take it for granted that physiological processes would be of a chemical and physical nature, in the seventeenth century this was the key issue at stake and several physicians and natural philosophers would have been reluctant to accept, or would have flatly denied, that complex processes like generation would occur without some immaterial guiding principle or agent—whether located in the body or more broadly in nature.

In one among his numerous publications on mechanism, *Discovering Cell Mechanisms*, philosopher William Bechtel provides a general definition of our term: "A mechanism is a structure performing a function in virtue of its components parts, component operations, and their organization. The orchestrated functioning of the mechanism is responsible for one or more phenomena."[2] Here the musical metaphor emphasizes the coordinated spatial and temporal organization of the components, though in most cases this orchestra would be playing without a conductor beating the time and ensuring the timely entry of its members. Earlier in the same work Bechtel states: "The key to the mechanistic approach was not the analogy of physiological systems to human made machines but the quest to explain the functioning of whole systems in terms of the operations performed by their component parts."[3] Bechtel has put forward a perfectly legitimate normative claim here. My concern is whether his contention is a useful starting point for a historical analysis. A few pages later Bechtel moves to some historical examples and provides the specific example of the heartbeat to exemplify his point. Bechtel seems to suggest that Harvey's understanding of the heartbeat was mechanistic, because it relied on the heart's component parts, such as ventricles and valves: "William Harvey had already offered his own mechanical pump model for the circulation of the blood. . . . Once Harvey established that the blood circulated, the need for a pump to move blood was recognized and the functioning heart was identified as the mechanism responsible for this phenomenon."[4] It is not clear from these passages whether Bechtel would attribute the notion that the heart as a whole is a mechanism to Harvey (1578–1657), or only that some aspects of its action can be seen as such. As is well known, Harvey believed in a "pulsative" faculty of the soul responsible for its contractions, which by his own standards was nonmechanical and immaterial.[5]

In a different passage Bechtel suggested a dichotomy: "Aristotelian philosophy in particular advanced an anti-mechanistic conception of nature. It emphasized *telos*, the end state to be achieved by entities of nature, and the form, which resided in bodies, and determined their nature and what they did."[6] Here mechanism is contrasted with teleology, though this dichotomy was typical of different times, such as the nineteenth century more than the early modern period, when—with the notable exception of Descartes and some of his associates—most mechanistic anatomists and natural philosophers, from Nicolaus Steno to Robert Hooke and Robert Boyle, accepted a teleological notion of mechanism seeing the body as a God-created machine. For Descartes laws of nature are due to God; the rest—including the elaborate organization of animals and the human body—follows from them.[7]

In a later passage Bechtel presents seemingly tortuous claims about the French anatomist Xavier Bichat (1771–1802):

> The significance of organization for biological systems was brought home in the nineteenth century by challenges from biologists who denied that mechanisms could account for the phenomena of life. These biologists, known as *vitalists*, highlighted ways in which biological systems function differently than non-biological systems. Xavier Bichat (1805) is an important example. In many respects, Bichat was pursuing a program of mechanistic explanation. He attempted to explicate the behavior of different organs of the body in terms of the tissues out of which they were constructed. He decomposed these organs into different types of tissues that varied in their operations and appealed to the operations of different tissue types to explain what different organs did. But when Bichat reached the level of tissues, he abandoned the mechanistic program.[8]

In fact, Bichat was opposed to what were generally seen as mechanistic explanations and distinguished among tissues based on their vital properties; physical properties are proper to matter, while vital properties disappear with death. At the time the doctrine of vital principles or forces, also called vitalism, and mechanism were routinely contrasted, so the claim that "Bichat was pursuing a program of mechanistic explanation" seems curiously anachronistic. Bichat thought that the activity of organs could not be understood simply by relying on the physical properties of their component parts without attending to the vital properties of those parts. He actively opposed the mechanistic program because he deemed it erroneous.[9] By the same token, if the defining feature of a mechanism is that it operates "in virtue of its components parts," Bechtel should argue that Aristotle and Galen too, despite their teleology, in crucial respects were "pursuing a program of mechanistic explanation" because they "attempted to explicate the behavior" of bodies in terms of the organs "out of which they were constructed." While Bechtel's approach may be adequate for systematic concerns and analyses of the role of mechanism in biology, more sophisticated tools are needed for a meaningful historical analysis.

Although reaching a historically sensitive understanding of the notion of mechanism is the goal rather than the presupposition of my investigation, this may be an appropriate place to provide some general criteria and suggest a provisional working definition. The notion of mechanism acquired different connotations over time, first encompassing and then rejecting teleology, for example. If a definition has to be historically useful it has to be historically sensitive. The problem with Bechtel's emphasis on components and dismissal of the analogy with artificial machines is that it does not reflect the historical actors' perception. Take for example Steno's discussion of the brain, in which the notion of machine is so intertwined with the idea of taking it apart in order to figure out how it and its components work that any idea of separating the two appears fraught with difficulties: "Now since the brain is a machine, we should not hope to find its artifice [*artifice*] by other ways than those one uses to find the artifice of other machines. There is therefore nothing left to do besides what would be done to any other machine, I mean to dismantle piece by piece all its components [*ressors* (*sic*)] and consider what they can do separately and together."[10] Moreover, in the tradition often characterized as "vitalist," living organisms involve chemical and physical processes differing from those unrelated to life, but they still have components—such as tissues, for Bichat. But according to Bechtel organisms and even individual organs would invariably be mechanisms, while the historical actors would have firmly opposed such a view as they would have contrasted vital properties with mechanism. Moreover, the notion of "vitalism" has a complex history deserving a careful study: the term entered philosophical discourse around 1800 and was used immediately afterward in a highly charged political, religious, and philosophical atmosphere making it ill suited to being employed unproblematically for earlier times—with regard to both the role of the soul and the existence of a unitary vital principle as opposed to a multitude of individual forces.[11] In conclusion, in this respect—though not necessarily from a contemporary philosophical perspective—dismissing the analogy with machines seems highly problematic.

For my present purposes, by *mechanism* I understand a material structure or an object, whether macro- or microscopic, whose operation depends exclusively on the spatial arrangement and motions of its component parts. Its mode of operation can be characterized as broadly mechanical, or akin to that of artificial machines, by which I include physical and chymical processes, as they were understood in the early modern period, provided they could actually or plausibly be given a mechanistic or machinelike account—though plausible and even widely accepted accounts could also be contentious.[12] An actual mechanism would be a fish's air bladder, whose operation would make it float or sink depending on the amount of air it contains according to Archimedean hydrostatics. A plausible mechanism would be the glomerulus in the kidneys, a structure whose operation would seemingly be the filtration of urine from arterial blood—though while the structure was identified through the microscope, its mode of operation was not proven empirically.[13]

A New Look at Mechanisms

A first step in a new direction involves a more careful analysis of our term. In *Discipline and Experience* Peter Dear has reminded us of the historical nature of the art/nature distinction and that "such categories as 'art,' 'nature,' and 'machine' are mutually interactive: their meanings change as their relationships are reconfigured." While discussing the statement "the world is a machine," Dear refers to the work of philosopher Mary Hesse, among others, supporting her view "that a metaphor is not merely descriptive of one concept in terms of another, but becomes constitutive of the meaning of both."[14] In light of these comments, it seems appropriate to look at the notion of mechanism not in isolation but together with changing notions of nature and machine and also with what could be called its evolving contrast class, including: in the early modern period faculties of the soul stemming from a classical background relying on Aristotle and Galen; in the eighteenth century, especially from the second third, vital properties relying not on immaterial souls but specific of living matter, which would differ from standard chemistry and physics; teleological explanations for part of the nineteenth; and lawlike explanations from the mid-twentieth, inspired by a philosophical outlook dominated by physics. Each of these periods would be worthy of a specific study in its own right. This schematic and crude periodization is not meant to pinpoint philosophical positions with chronological accuracy but to highlight the shifting intellectual horizons within which our term was framed and conceptualized. Joining a definition of mechanism with that of its contrast class presents several advantages to a more historicist analysis while avoiding the pitfalls of adopting a definition and projecting it into the past with scant regard to the historical actors' approach.

However, also having recourse to the notion of contrast class could be problematic, especially in dealing with the early modern period. The danger is that of seeing a complex intellectual situation in dichotomous terms, lumping together a wide range of positions that should be carefully analyzed in their own right and distinguished from each other. I consider three issues: the first is the interpretation of a number of problematic notions intersecting the understanding and definition of mechanism; the second can be characterized as "suspension of judgment," namely the recognition that on at least some occasions, some seventeenth-century scholars expressed doubt and uncertainly over specific issues and saw mechanistic interpretations more like a project or even a question rather than like a settled matter; lastly, I will address the issue of what I call global versus local accounts, highlighting the need to consider both perspectives if we want to reach a balanced view.

In some circumstances authors used ambiguous terms whose meaning was unclear and which may have been interpreted differently by their contemporaries; expressions like "active volatile particles" could mean very small particles that are very mobile in view of their diminutive size, but it could also mean particles qualitatively different from other forms of matter in that they cannot be brought to rest because they are endowed with a special activity. Likewise, the notions of "ferments" and "active principles" follow the ambiguity of chymical processes: one could interpret them strictly mechanistically, as Descartes did, but they could also have different connotations stemming from their Paracelsian and Helmontian origins and implying an intrinsic activity in matter or the presence of immaterial principles.[15] Similarly, the expressions "seminal principles" and "plastic powers" could refer to an immaterial property related to the process of generation, but they could also be "mechanized," as a shorthand for a series of mechanical processes associated with the motion and textures of portions of matter of different sizes, as we are going to see in the final chapter. Many natural philosophers had recourse to plastic powers in discussing the formation of living organisms and implying finality, though both aspects were missing in Robert Hooke's usage of "plastick virtue" in discussing snowflakes.[16] And lastly, even the notion of soul could refer to an immaterial principle, a material one, or a combination of the two.[17]

An additional interpretative problem stems from what could be characterized as "suspension of judgment." Many early modern authors were painfully aware of the limitation of their knowledge and of the fact that in many instances plausible explanations, whether mechanistic or not, were unavailable. Of course, at times suspension of judgment could be a tactical move, though at least at times it seems legitimate to take it as genuine. In such circumstances a cautious author such as Robert Boyle, for example, could offer a general interpretative framework while "black-boxing" the specific problem until all the details had been clarified—if they could be; this is the strategy he employed with regard to atomism versus the infinite divisibility of matter, by refusing to adjudicate the issue and talking of the corpuscular philosophy instead, which often sufficed for the issues at hand. Moreover, suspension of judgment could have genuinely different implications: in some cases, authors had already accepted a mechanistic framework; therefore, the issue was one of determining which specific mechanisms were at play. Borelli, for example boldly affirmed the mechanical nature of several processes, such as the filtration of urine in the kidneys, even when he had no precise idea how they actually worked and could only propose plausible analogies.[18] In other cases, however, the mechanistic framework was in question, perhaps even looked implausible; therefore the issue was to decide between a mechanistic and an alternative account, possibly based on the role of the soul and its faculties, or on the belief that nature followed different laws in processes occurring in living organisms, compared to those of standard physics and chemistry.

Lastly, often historians have privileged authors' general worldviews over their explanations of specific processes. The mechanistic program is meant to be comprehensive, involving all phenomena in nature and specifically bodily processes, rather than piecemeal, about this or that case; thus, if our authors reject that specific processes would occur mechanistically, they would be antimechanists. The issue of which natural philosopher would truly be a mechanist is a long-standing one in the history of philosophy; recently Daniel Garber has adopted this approach in assessing a number of major seventeenth-century figures.[19] This approach, however, obscures the progressive identification of mechanisms in specific areas: after all, to offer a mechanistic perspective involves not only making a grand philosophical statement but also providing detailed accounts of specific phenomena—such as, just to mention a few notable cases in the history of mid-seventeenth-century anatomy, the operation of the valves in the heart and in the veins, the pulsation of the arteries, or the motion of chyle in the thoracic duct and of lymph in the lymphatics.

Knowledge of unidirectional valves dates from antiquity, when Erasistratus described the valves in the heart in terms echoing those used for recent technological devices, such as a two-chambered water pump equipped with four sets of unidirectional valves invented by the engineer Ctesibius, as Heinrich von Staden has shown;[20] the explanations of the role of the valves in the veins and the pulsation of the arteries were due to Harvey: in the former case, he compared the valves to sluices in rivers and performed experiments with a probe in a cadaver, showing their role in allowing unidirectional flow toward the heart; in the latter case, he repeated Galen's difficult experiment of the reed in the artery—tying a portion of an artery to a reed inserted into it—and challenged his interpretation that the arteries pulsate because of a faculty transmitted by the heart, arguing instead that they have a purely passive mechanical role and expand because of the impulsion of blood like inflated bags or gloves. As Peter Distelzweig has recently reminded us, Harvey's overall views were emphatically not mechanistic and his limited mechanistic accounts were part of an overall neo-Aristotelian and neo-Galenic approach: the example of the pulsation of the arteries "is *not* an instance of a systematic effort to eliminate Galenic Faculties." In this specific instance, however, Harvey did refute Galen's account based on the transmission of the heart's pulsative faculty: here it is helpful to look at his philosophical views as a whole as well as at his explanation of individual local mechanisms.[21]

Unlike Harvey, Jean Pecquet was a mechanist anatomist who provided an account of the motion of chyle in the thoracic duct without having recourse to what he considered inexplicable attractions, relying instead on physical notions involving the "elatery," or elasticity, of the fibers and vessels due to respiration and digestion. Thus, one could say that he envisaged a mechanism involving chyle moving from its receptacle between the kidneys, through the thoracic duct, to the subclavian vein, where it enters the bloodstream; valves throughout the thoracic duct prevent backflow, while valves in the jugular veins prevent chyle from entering the vena cava—thus those valves would relate to the chyliferous vessels.[22]

The risk of privileging the global approach over the local one is to overlook the substantive shift from accounts relying overwhelmingly on the faculties, as with many derived from Galen's *On the Natural Faculties*, for example, to those relying largely or even overwhelmingly, though not exclusively, on mechanisms; both global accounts, strictly speaking, would be nonmechanistic, though this approach may hide a huge shift from faculty-oriented to mechanistic types of explanation.

These reflections highlight the problematic nature of a strictly dichotomous perspective and call for a more nuanced approach. Moreover, while it is important to reconstruct an author's overall perspective, it seems also rewarding to choose as one's focus a specific problem and the way different investigators addressed it. I will revisit these claims, first by taking a look back at Galen's opinions and then by examining a number of tensions in the early modern mechanistic program.

Intermezzo: Galen of Pergamon

In the early modern period Galen's status was such that his views would have been widely known and highly influential on Harvey, for example, and the entire anatomical tradition; interpreting his writings was a crucial aspect of the dispute between Giovanni Girolamo Sbaraglia and Marcello Malpighi, which started around 1690 and ended after Malpighi's death in the early 1700s.[23] My aim here is not to offer novel perspectives on Galen but more modestly to survey some of his opinions in relation to some of the themes we have examined so far, so they can serve as a term of comparison for later views. We are going to encounter limited examples of mechanistic explanations, key terms whose meanings could shift in significant and perhaps even dramatic ways, and cases of suspension of judgment, when Galen—by no means a shy or modest man—candidly admitted that despite extensive investigations, he had no answer.

Galen's views were uncompromisingly teleological; he consistently opposed the atomists' notion that chance played any significant role in nature: at times he refers to a demiurge, other times to nature, even in the same text, such as the last book of *On the Usefulness of the Parts of the Body* (*De usu partium*), leaving readers to wonder what exactly he meant.[24] Galen also opposed mechanistic views, whereby nature would operate as in artificial machines; his understanding of bodily processes relied overwhelmingly on nonmaterial faculties of the soul or of nature.

Even so, it is possible to identify in his writings examples of specific localized processes working mechanically, though admittedly they take a minor role. *On the Natural Faculties* (*De naturalibus facultatis*) is one of the most explicit attacks on the views of the anatomist Erasistratus (3rd century BCE) and the physician Asclepiades of Bithynia (1st century BCE), even by Galen's rather brash and aggressive standards. In it, Galen attacks mechanistic views forcefully, arguing in favor of the notion that nature operates through the faculties of genesis, growth, and nutrition; her operations cannot be imitated by human art, and there is a radical distinction between nature's and human productions. Galen presents two examples that at first seem to exemplify growth, though they do so only deceptively and ultimately unsuccessfully: children playing with pig bladders, heating them in the ashes of a fire to make them grow, do not produce real growth, because the bladders lose in thickness what they gain in surface. Similarly, weaving too might simulate growth, though in reality real growth involves what is already there, a liver is already a liver before growing; by contrast, a wicker basket is not a basket until it is completed.[25]

Yet even in *On the Natural Faculties*, Galen discusses instances of processes occurring without any action of the faculties, mechanistically, such as preventing the flow of fluids through mechanical obstruction, deglutition, or by purely physical means, such as attraction due to nature's repugnance of empty space or *horror vacui*, as claimed by Erasistratus.

In the case of the kidneys and ureters Galen adopts different types of explanation: in his opinion the kidneys draw urine not mechanistically through filtration but through the action of the faculties by sympathetic attraction; by contrast, the unidirectional flow of urine from the kidneys to the bladder is due to the mechanical arrangement of the parts, specifically the angle with which the ureters are inserted in the bladder and a membrane preventing reflux, with an arrangement that some seventeenth-century anatomists, including Harvey, described as being "like a valve." Galen showed that urine flows from the kidneys to the bladder with a vivisection experiment in which he applied a ligature to the ureters, which led to the accumulation of urine between the ligature and the kidneys. He also proved that the reflux of urine to the kidneys occurred neither in a living nor in a dead body through an experiment in which he applied a ligature to the penis, showing that even in such circumstances urine did not flow back.[26]

In the case of deglutition Galen argued that the stomach has two types of fibers, straight and circular: straight fibers attract; circular fibers do not. The intestine and the esophagus have only circular fibers that exert no attraction. Galen supports this claim by a rather unpleasant experiment relying once again on a dead body: deglutition occurs "mechanistically," as when matter goes through a narrow passage, as one can show by pouring water into the throat of a cadaver:

> For what alone happens, as Erasistratus himself said, is that when the upper parts contract the lower ones dilate. And everyone knows that this can be plainly seen happening even in a dead man, if water be poured down his throat; this symptom results from the passage of matter through a narrow / channel; it would be extraordinary if the channel did not dilate when a mass was passing through it. Obviously then the dilatation of the lower parts along with the contraction of the upper is

> common both to dead bodies, when anything whatsoever is passing through them, and to living ones, whether they contract peristaltically round their contents or attract them.[27]

The dead body retains its basic structure for some time, enabling Galen to use it not simply in order to investigate the arrangements of the parts, as in anatomy, but as an experimental apparatus to show that certain processes are not necessarily associated with life and the faculties—in this case attraction—but result from the conformation and features of the parts. The cadaver appears here as an object *sui generis* with an ambiguous status, because it is no longer a human body, yet it is not artificial either, like a human-made machine; thus, in some very specific respects creations of nature and art can behave similarly.[28]

In a later passage Galen argues that there are two types of attraction: that of bellows, which is based on the notion of *horror vacui* whereby a vacuum gets filled and which can be seen as mechanical; and that of the magnet, which is due to the "appropriateness of quality" and is more akin to selective attraction typically found in bodily processes. Despite obvious differences with living bodies, Galen finds the magnet an especially appealing example of selective attraction, one that cannot be explained by means of Epicurean atoms but that provides powerful empirical evidence of the processes he envisages in the body. The scarce attraction of food by the arteries which go to the stomach and the intestine is an example of the process based on *horror vacui,* this being the reason why so little nutriment goes from the stomach to the arteries, because this type of attraction works only with lighter matter; namely, only the scarce, more refined nutriment:

> These arteries cannot get anything worth speaking of from the thick, heavy nutriment contained in the intestines and stomach, since they first become filled with lighter elements. For if you let down a tube into a vessel full of water and sand, and suck the air out of the tube with your mouth, the sand cannot come up to you before the water, for in accordance with the principle of the refilling of a vacuum the lighter matter is always the first to succeed to the evacuation.
>
> It is not to be wondered at, therefore, that only a very little [nutrient matter] such, namely, as has been accurately elaborated—gets from the stomach into the arteries, since these first become filled with lighter matter. We must understand that there are two kinds of attraction, that by which a vacuum becomes refilled and that caused by appropriateness of quality; air is drawn into bellows in one way, and iron by the lodestone in another.[29]

Here Galen accepts that the *horror vacui* of Erasistratus does occur in the body in special circumstances, though Erasistratus would wrongly generalize such limited examples to all types of attraction. As Sylvia Berryman has pointed out, there are further comparisons between body parts and artificial machines, such as tendons and threads used in marionettes, articulation joints and pulleys, the spine and a ship's keel, the skull and a helmet, and connecting bones with serrated saws.[30]

If we now move to some of Galen's key notions, we see that in some instances they present major ambiguities. The term *dunamis*, for example, usually translated as "faculty," plays a fundamental role in Galen, despite the fact that some of its defining features are problematic and mysterious. The term was used by Aristotle in relation to the soul, understood as the form of living bodies, both animals and plants: faculties would indicate the powers, activities, or capacities of the soul. In Aristotle's time the nervous system had not been properly identified and Aristotle attributed a key role to the heart, the brain being mainly a refrigeration system, larger in humans than animals, and in men than women, because humans are hotter than other animals, and men than women.[31]

The situation changed with the anatomical discoveries made in the third century BCE at Alexandria. Galen relied on these transformations: *On the Natural Faculties* distinguished between faculties of the soul, related to perception and motion—which would pertain to animals endowed with a nervous system—from the natural faculties, which are not related to the soul and pertain to plants as well. Besides genesis, nutrition, and growth, Galen discussed the attractive, repulsive, retentive, and transformative faculties, all relating to the previous ones. A faculty of the soul would be located in the animal; by contrast, it seems plausible to consider the natural faculties as dependent on the properties of matter of living organisms in general, thus located in nature more broadly. Galen seems to be developing Stoic themes here, adopting a tripartite approach whereby some processes are common to all bodies, whether living or not; some low-level activities are characteristic of living bodies but depend only on general properties of living matter; and, finally, some activities, such as sensation and motion, depend on the soul attached to individual animals. In the late work *On My Own Opinions* (*De propriis placitis*), however, Galen underplays the significance of the shift from faculties of the soul to faculties of nature and suggests instead that in *On the Natural Faculties* he had referred to nature rather than the soul only because the tract was addressed to ordinary doctors (*medicis popularibus*).[32]

These issues are tied to broader interpretative problems to do with the nature of the soul and its faculties. Although Galen patiently explored different alternatives and seemingly shifted his allegiances over time, he often left his views on these matters undetermined. Overall, he saw an unbridgeable difference between human artifacts and nature's productions; however, while he repeatedly stated his confidence in the existence of the soul, he was unsure whether the soul was material or immaterial, mortal or immortal. While from a strictly medical standpoint such views may not be of central importance, they certainly are from a philosophical perspective focusing on life and its properties. Despite the abstract nature of these issues, Galen sought to answer at least some of them through empirical means. For example, in his major treatise *On the Opinions of Hippocrates and Plato* (*De placitis Hippocratis et Platonis*), he debates whether *pneuma* (a mixture of air and fire) is the soul or its instrument. From a gruesome vivisection experiment, cutting and damaging an animal's brain, Galen observes that the loss of *pneuma* leads to the loss of sensation and motion, though not of life, since the animal can recover. Hence, he could conclude that *pneuma* is not the substance of the soul, because its loss would lead to death, but only the soul's first instrument—whatever the soul may be.[33]

Similar interpretative problems involve not only the nature of the soul but also its faculties. The mixture, or *krasis*, of the humors and their qualities could be responsible for processes that cannot be produced by us; in this sense the faculties, whether of nature or the soul, could be due to such mixtures. Mixtures play a key role in a range of physiological processes; they could be made only by nature or the demiurge, not by us. Thus, the issue is whether the faculty is the actual *krasis* or whether the *krasis* is its instrument, much like *pneuma* and the soul. At times, as in *On Mixtures* (*De temperamentis*), Galen suggests that there is something more to the construction of our body than the humoral qualities, however combined; those qualities would be the instruments of a higher, more divine, cause:

> A second mistake is the failure to regard the natural cause of our construction as a craftsmanlike faculty [*dunameos*], whereby the parts are formed in a way suited to the characters of our souls. This was a point on which even Aristotle was in some doubt: should this faculty not be attributed to some more divine cause, rather than just to hot, cold, dry, and wet? Those who rush to make simplistic statements of this greatest of issues, and explain construction purely in terms of the humoral qualities, seem to me to be in error. The latter are surely only the instruments, whereas the cause responsible for construction is something different from them.[34]

However, in one of his last works, *The Capacities* [or *Faculties*] *of the Soul Depend on the Mixtures of the Body* (*Quod animi mores corporis temperamenta sequantur*), Galen returns to the topic; following Plato, he accepts a tripartite soul located in the liver, heart, and brain, and claims that the first two are mortal. He leaves undecided whether the third is mortal—though in fact he strongly suggests that it is; he also strongly suggests—without, however, formally committing himself to this opinion—that the tripartite soul and its faculties are precisely the *krasis* of the four qualities, hot, cold, dry, and humid. As Galen puts it:

> Now, if the reasoning form of the soul is mortal, it too will be a particular mixture, [namely] of the brain; and thus all the forms and parts of the soul will have their

> capacities dependent on the mixture—that is, on the substance of the soul; but if it is immortal, as is Plato's view, he would have done well, himself, to write an explanation as to why it is separated when the brain is very cooled, or excessively heated, dried or moistened—in the same way that he wrote the other matters relevant to it. For death takes place, according to Plato, when the soul is separated from the body. But why great voiding of blood, the drinking of hemlock, or a raging fever, causes this separation, I would have certainly have wanted to learn from him, if he were himself alive.[35]

Thus, the rational soul too joins a list of problematic and ambiguous notions that could be used and interpreted in radically different ways, especially whether it is a mortal mixture of qualities, hot, cold, dry, wet, or of bodies with those qualities, or how it could be immortal and yet crucially dependent on bodily processes.

The Galenic corpus is among the largest extant in ancient Greek; my account does not even begin to do justice to its richness and complexity. Nevertheless, even from our limited perspective, we have seen examples of his reliance on limited physical/mechanical explanations within an emphatically nonmechanistic framework, conceptual and terminological problems and ambiguities, and his extensive reliance on suspension of judgment on major philosophical issues.

Interpretative Tensions

Returning to the early modern period after this brief Galenic excursus, we identify a number of tensions affecting the mechanistic program not entirely unrelated to some of the problems we have just encountered. Both early modern authors and their recent interpreters have struggled with definitions, projects, and practices; as we are going to see, these issues are profoundly interrelated. While in some cases mechanistic accounts were discussed in the abstract, here I focus on more concrete and specific practices.

In some instances, the problem was to make sense of the same devices that could be seen in a different light by different people and over time, as living or mechanical, for example, as Vera Keller has reminded us in the case of Dutch inventor Cornelis Drebbel. At times just naming such devices—a perpetual motion machine, a cosmoscope, or a thermoscope, for example—would frame them within a different interpretative system. Magnetic devices had an especially ambiguous status since Galen, but even watches could be seen as alive by someone unfamiliar with their construction, as Boyle had argued polemically against Henry More: "If I had / been with those Jesuites, that are said to have presented the first watch to the King of China, who took it to be a living Creature, I should have thought I had fairly accounted for it, if, by the shape, size, motion, &c. of the Spring-wheels, balance and other parts of the watch I had shewn, that an

Engine of such a structure would necessarily mark the hours, though I could not have brought an argument to convince the Chinese-Monarch, that it was not endowed with Life."[36]

A major topic in contemporary debates involves the level of mechanical explanation, an issue with problematic implications also in the early modern period. Some very strict interpretations of the mechanical philosophy would involve only the size, shape, and motion of particles. This would be a rather narrow set of tools on the basis of which it would be exceedingly difficult to explain even some basic properties of matter, such as its solidity, let alone more special ones, such as those associated with chymical properties, for example, or elasticity, one stemming from antiquity and which Leonardo also explored but which rose to prominence in the second half of the seventeenth century. We are so used to it that we take it for granted; yet elasticity is a strange and complex property affecting solid bodies, such as a piece of coiled metal, rebounding billiard balls, and gases bound in a container; in either case, matter seems to have a memory of its previous state and a tendency to return to it. Despite its ubiquity, even today few people would be able to provide a vague account of why a bent metal bar seeks to return to its original position, let alone explain it. Elasticity relates to anatomy too, since the arteries and other body parts are elastic, as Jean Pecquet pointed out in 1651.[37]

How would seventeenth-century natural philosophers try to explain it in terms of size, shape, and motion of particles? Descartes boldly attempted to explain elasticity through the motion of particles—but Descartes boldly tried to explain most things that way. However, as Barnaby Hutchins has recently argued, even Descartes was far from adopting this approach consistently.[38] Finding a way to account for elasticity was a challenge: was it mechanical, if no empirically based explanation in terms of the size, shape, and motion of particles and components was forthcoming? In *De potentia restitutiva* (1678), for example, Hooke puts forward a hypothesis to account for elasticity in terms of the "congruity and incongruity" among bodies, by which he understands "an agreement or disagreement of Bodys as to their Magnitudes and motions."[39]

We may approach the matter from a different perspective, not in terms of the component parts and internal organization of an elastic body but rather in terms of plausibility and analogy with mechanical devices. In the 1670s both Hooke and Christiaan Huygens designed spring-regulated watches, relying on the notion that the oscillations of a spring are isochronous—that they occur in equal times regardless of their amplitude. In *Horologium oscillatorium* (1673) Huygens had shown that the oscillations of a pendulum clock constrained by cycloidal cheeks were also isochronous: in both cases at each point the force was proportional to the displacement. Thus, a spring-regulated watch behaved like, or was

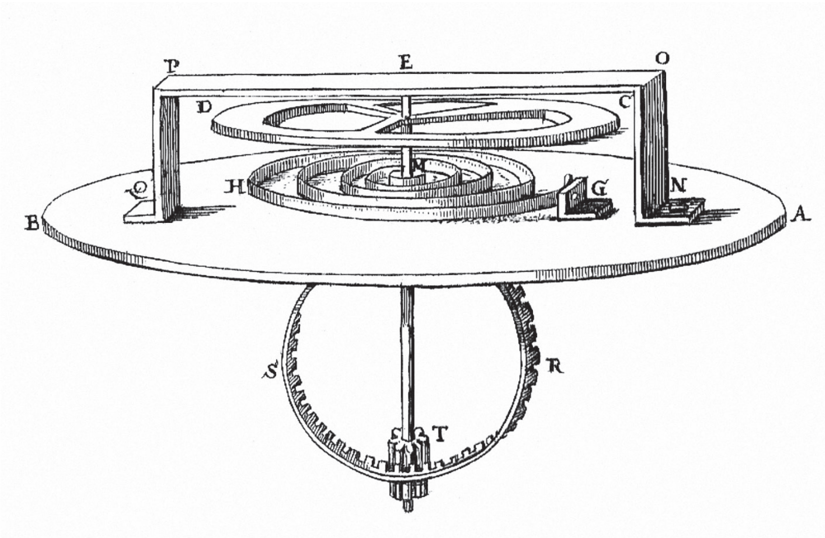

Fig. 1.1. Spring-regulated watch. Huygens, "Extrait d'une letter" (1675). Courtesy of the Lilly Library.

equivalent to, a pendulum clock, an updated version of an archetypal mechanical device that was explicitly described in the review of *Horologium oscillatorium* in the *Philosophical Transactions* as a "Mechanism" (fig. 1.1). Arguably, once springs entered the design of the archetypal mechanical device, the question of whether elasticity was mechanical appeared in a different light. Similarly, in referring to water fountains operating by the spring or elasticity of the air, Hooke mentions the "great number of uses that are and may be made of Springs in Mechanic Contrivances."[40]

Thus, the situation in those decades was evolving in such a way that practices, analogies, and inferences, in addition to attempts at detailed explanations of microcomponents, affected the plausibility of mechanistic accounts and the very domain of mechanics. The Jesuit Claude François Milliet Dechales (1621–1678), for example, devoted the eighth book of *Cursus seu mundus mathematicus* (1690) to *elaterium*, or elasticity: after seven preliminary propositions debating its physical nature, he produced thirty mathematical theorems on the collision of bodies. The entire book, however, is part of a section on mechanics, sandwiched between one on the force of percussion and one on statics: whatever account one could give of the internal organization of bodies, elasticity had become part of mechanics.[41]

Elasticity plays an important role in Boyle's work as an example among others of a mechanical affection of matter. Boyle put matters this way in the 1666 *On* *the Origine of Forms and Qualities According to the Corpuscular Philosophy*, a text Henry Oldenburg presented as an "*Introduction* to the *Principles* of the *Mechanical Philosophy*":

> That then, which I chiefly aime at, is to make it Probable to you by / Experiments, (which I Think hath not yet beene done:) That allmost all sorts of Qualities, most of which have been by the Schooles either left Unexplicated, or Generally referr'd, to I know not what Incomprehensible Substantiall Formes; may be produced Mechanically, I mean by such Corporeall Agents, as do not appear, either to Work otherwise, then by vertue of the Motion, Size, Figure, and Contrivance of their own Parts, (which Attributes I call the Mechanicall Affections of Matter, because to Them men willingly Referre the various Operations of Mechanical Engines:) or to Produce the new Qualities exhibited by those Bodies their Action changes, by any other way, then by changing the Texture, or Motion, or some other Mechanical Affection of the Body wrought upon.[42]

In a recent essay Garber cites the same passage but then curiously he focuses only on motion, size, and figure, omitting to discuss explicitly the notion of contrivance. Arguably contrivance could be accounted for in terms of motion, size, and figure, yet it is intriguing that Boyle lists it together with the other three, as if the relation between contrivance and the other notions was problematic. Later in the same text Boyle argues that engines perform their operations by virtue of the material properties of their parts, emphasizing once again his dislike of substantial forms and preference for a body's four mechanical affections: "And if several Active Qualities convene in one Body, (as that which in our Hypothesis is meant by Forme, usually comprises several of them,) what great things may be thereby perform'd, may be somewhat guess'd at by the strange things we see done by some Engines which, being, as Engins, undoubtedly devoid of Substantial Forms, must do those strange things they are admir'd for, by virtue of those Accidents, the / Shape, Size, Motion, and Contrivance, of their parts."[43]

Boyle is traditionally very guarded: he states that he makes it "probable" that "almost all" qualities "may" be produced mechanically. Here, as in the previous passage, he includes "contrivance" together with shape, size, and motion among the "Mechanicall Affections of Matter." At the time this notion was closely tied to that of mechanism, especially in Hooke's *Micrographia* (1665), which appeared the year before Boyle's *Origine.* This notion plays an important part in Boyle's account: at times he seems to imply the macroscopic arrangement of the parts of an object, as in a clock; other times he has in mind their internal microscopic arrangement, determining their texture. In the latter case, however, how one could explain the cohesion, elasticity, and similar properties of bodies was a problematic matter.[44] Arguing against Henry More's hylarchic principle, which was an incorporeal agent allegedly explaining Boyle's hydrostatic experiments, Boyle explicitly counted "spring" and "weight" among the mechanical affections of matter: "Such Mechanical Affections of matter, as the Spring and Weight of the Air, the Gravity and Fluidity of the water and other Liquors, may suffice to produce and account for the Phaenomena without recourse to an Incorporeal Creature."[45]

We face here the first tension concerning what we could call the transition across different levels of mechanistic explanation: seventeenth-century discussions differ from more recent ones because at the time it was unclear and also contentious whether the different levels would be amenable to mechanistic explanations at all. In a remarkable passage from *The Excellency of Theology Compar'd with Natural Philosophy* (1674), Boyle states:

> And though *Nature* (or rather its Divine Author) be wont to work with much finer materials, and employ more curious contrivances than *Art,* (whence the Structure even of the rarest Watch is incomparably inferiour to that of a Humane Body;) yet an Artist himself, according to the quantity of the matter he imploys, the exigency of the design he undertakes, and the bigness and shape of the Instruments he makes use of, is able to make pieces of work of the same nature or kind of extremely differing bulk, where yet the like, though not equal, Art and Contrivance, and oftentimes Motion too, may be observ'd.[46]

After providing some specific examples, Boyle continues with a passage echoing one from Hooke's *Micrographia*: "And therefore to say, that, though in Natural Bodies, whose bulk is manifest and their structure visible, the Mechanical Principles may be usefully admitted, that are not to be extended to such portions of Matter, whose parts and Texture are invisible; may perhaps look to some, as if a man should allow, that the Laws of Mechanism may take place in a Town-Clock; but cannot in a Pocket-Watch."[47] As Hooke had put it in *Micrographia*: "We know there may be as much curiosity of contrivance, and excellency of form in a very small Pocket-clock, that takes not up an Inch square of room, as there may be in a Church-clock that fills a whole room."[48] Boyle is very forthcoming here in arguing that "Mechanical Principles" or the "Laws of Mechanism" can be extended from known visible structures to unknown invisible ones. Overall, however, such a move was seen as problematic at the time and more recently has been hotly debated by historians.[49]

In some cases, the issue was not even one of moving across levels of mechanistic explanations but to provide some form of a mechanistic account in the first place. Despite the huge increase in the mechanical devices available in the seventeenth century, the range of conceptual and material tools available was comparatively limited, as Malpighi lamented. How could investigators hope to account for complex processes formerly seen as related to the natural faculties of nutrition, growth, and generation, or processes of secretion, muscle contraction, and sensory perception? At times anatomists could provide only partial and limited explanations. In the case of secretion, for example, the precise mechanism involved eluded Malpighi; however, in some cases he provided some partial explanations by identifying what he called "glands," or structures within a number of organs where the process would occur. Some, as in the cerebral cortex, proved to be artifacts of his preparation techniques; others, as in the kidneys, proved fertile for further studies. In the case of growth, Malpighi envisaged a process analogous to weaving, and identified structures resembling textiles in bone and plants.[50]

An aspect related to the level of explanation concerns the role of macroscopic versus microscopic components. In the preface to *Micrographia* Hooke outlines the mechanistic program he associated with instruments enhancing the senses, and especially the microscope. Referring to members of the Royal Society, he states:

> By this means they find some reason to suspect, that those effects of Bodies, which have been commonly attributed to Qualities, and those confess'd to be occult, are perform'd by the small Machines of Nature, which are not to be discern'd without these helps, seeming the meer products of Motion, Figure, and Magnitude; and that the Natural Textures, which some call the Plastick faculty, may be made in Looms, which a greater perfection of Opticks may make discernable by these Glasses; so as now they are no more puzzled about them, then the vulgar are to conceive, how Tapestry or flowred Stuffs [textile fabrics] are woven.[51]

Here Hooke ties the ability of instruments to enhance vision to an explicit anti-Aristotelian agenda, uncovering behind occult inexplicable qualities and plastic faculties nothing but motion, figure, size, and textures or the material conformation and arrangement of the constituent parts; he argues that the learned would be no more puzzled by those natural textures than common people are by the woven structure of fabrics. Although his simile in this passage seems purely rhetorical, in fact it was quite adroit because weaving was a common mechanical analogy in the study of plants and animals stemming from antiquity, at least from Erasistratus. Hooke himself identified the structure of some leaves as resembling a textile: "the smooth surfaces of other Plants are otherwise quilted, Nature in this, as it were, expressing her Needle-work or imbroidery." Malpighi too repeatedly adopted similar views relying on textile analogies in trying to grasp nature's operations, such as growth, for example.[52]

In a recent essay dealing specifically with generation, Karen Detlefsen has put the matter thus: "For my purposes, I define mechanism as the belief that all changes at the phenomenal level—that is, all changes we experience—are due to the lawful motion and contact of sub-visible matter that is inherently inert and quantitatively, not qualitatively, defined."[53] Detlefsen's definition fits well with Hooke's claim. However, her requirement is very strict: in the seventeenth century many mechanisms (such as the valves in the veins and milky veins, and the components of a clock or a mill) involved macroscopic components and did not require descending to a subvisible level. In *Origine of Formes and Qualities* Boyle put the matter thus with regard to a lock:

> That was onely a Piece of Iron, contriv'd into such a Shape; and when afterwards he made a Key to that Lock, That also in it self Consider'd, was nothing but a Piece of Iron of such a Determinate Figure: but in Regard that these two Pieces of Iron might now be Applied to one another after a Certain manner, and that there was a Congruitie betwixt the Wards of the Lock and those of the Key, the Lock and the Key did each of them now Obtain a new Capacity and it became a Main part of the Notion and Description of a Lock, that it was capable of being made to Lock or Unlock by that other Piece of Iron we call a Key, and it was Lookd upon as a Peculiar Faculty and Power in the Key, that it was Fitted to Open and Shut the Lock, and yet by these new Attributes there was not added any Real or Physical Entity, either to the Lock, or to the / Key, each of them remaining indeed nothing, but the same Piece of Iron, just so Shap'd as it was before.[54]

In some respects Boyle's passage echoes Hooke's *Micrographia*, which had been published the previous year. While Hooke emphasized miniaturization, however, Boyle emphasized the spatial relations between lock and key, which taken together could be seen as a contrivance or mechanism. This rather complex passage has attracted considerable attention to Boyle's views on relations; my interests here are centered on Boyle's reliance on macroscopic objects to account for qualities. To be sure, Boyle goes on to provide other examples involving microscopic effects; nevertheless, Detlefsen's emphasis on the shift from a visible to a subvisible level, while appropriate to her topic, seems too restrictive for a wider study.[55]

Finally, I wish to address the tension between human artifacts and nature's or God's creations. It was a common rhetorical trope to compare the two, as we have seen in the previous passage by Boyle, except that the latter were deemed superior, perhaps incomparably so, to the former: even within the limitations of matter, God worked with a perfection that humans could not imitate for any size, and of course those levels were severely limited for humans, while God operated freely with them. In *A Discourse of a Method*, for example, Descartes argues that many motions of the human body can occur without the consent of the will, and then continues: "Which wil seem nothing strange to those, who knowing how many Automatas or moving Machines the industry of men can make, imploying but very few pieces, in comparison of the great abundance of bones, muscles, nerves, arteries, veins, and all the other parts which are in the body of every Animal, will consider / this body as a fabrick, which having been made by the hands of God, is incomparably better ordered, and hath more admirable motions in it then any of those which can be invented by men."[56]

Here, as in other passages by Descartes and his contemporaries, God's creation is presented as "incomparably better ordered" than not only human actual creations but also any that "can be invented" by us. Thus, while in some respects a plant or an animal would resemble a human-made machine, because it would lack a soul and the faculties, in other respects there would be an unbridgeable gap of complexity between the two. Presenting matters this way raises the issue of whether it makes sense to compare human and divine/natural productions; the point of establishing a parallel between them is to show their similarity. However, introducing a distinction between such different artisans as humans and God runs the risk of transforming a quantitative into a qualitative difference, one potentially reinforced by having recourse to the notion of infinite perfection. Leibniz argued along these lines, raising the question as to whether an infinitely complex and perfect God-created machine, one that therefore cannot be imitated by human hands, would still be a machine in any meaningful way. The language of infinite complexity and perfection reintroduces troubling differences that the talk of machines was meant to erase.[57]

Concluding Reflections

The extensive reflections and investigations on the notion of mechanism in the early modern period require careful handling. I have argued that it is helpful to consider the notion of mechanism not only in isolation, or even together with its shifting contrast class, but also in a not-dichotomous fashion in relation to the meaning and usage of a cluster of other potentially related key terms. We have seen that a number of terms and expressions, such as "volatile active particles," "fermentation," "plastic powers," "seminal principles," and "soul," could be ambiguous and had shifting meaning. Moreover, the intellectual world was not divided in a Manichean fashion: it is necessary to consider a range of positions both within the mechanical philosophy and, more broadly, intersecting it.

At times authors, from Galen in antiquity to early modern ones, adopted suspension of judgment as a cautious strategy when they knew no better, leaving matters undecided; for some, mechanistic accounts offered plausible explanations within a limited domain in a broader nonmechanistic framework; for others the mechanical philosophy raised legitimate and genuine questions—as Dennis Des Chene has convincingly argued, it was an investigative project rather than an ontological dogma.[58]

I have also identified a cluster of problems associated with a discourse on mechanism. An account based exclusively on the identification of mechanisms, ignoring the broader intellectual horizon within which anatomists operated, would be one-sided and misleading and would present history as a progressive linear march of successive mechanical interpretations. However, focusing exclusively on that intellectual horizon would also be misleading because it would ignore the progressive shift toward mechanistic explanations in investigative practices, in the form of solving specific problems relying on the available tools.

In recent decades we have come to recognize that the mechanical philosophy was not a monolith molded by Descartes in terms of the size and shape of particles in motion and left unchanged for decades but a set of evolving and problematic views and projects whose contents and boundaries were puzzling and contested and which could be adopted piecemeal and shaped by different authors according to their needs and intellectual inclinations. We can make sense of the notion of mechanism within this fluid framework rather than by setting fixed and anachronistic criteria. I hope that these reflections and hermeneutical strategies may prove useful to historians and philosophers investigating similar problems in different periods, and to those studying the notion of mechanism in contemporary scientific practice. The notion of mechanism is deeply embedded in the intellectual texture and debates of successive periods; the historian wishing to make sense of our notion at a certain time cannot study it in isolation but needs to reconstruct the intellectual world of that time.