Final Causes and the Clockwork Universe: The Mechanistic Worldview

Peter McLaughlin

Abstract Although the final causes banished from science by Descartes and his generation were quickly readmitted by the next generation, there is some significant truth to the traditional story that modern science excluded final causes for nature. An analysis of the mechanistic world picture or the clockwork model of the universe shows that the irrelevance of final causes is a consequence of that picture or model. A clock, unlike a mill or a loom, does not produce anything. The clockwork is a transmission mechanism that does not turn a grindstone or otherwise perform useful work, but rather runs idle. Even such an advocate of final causes as Leibniz, distinguished categorically between an (ideal) 'physical' *perpetuum mobile*, like the world system, and an (absurd) 'mechanical' *perpetuum mobile* that could run perpetually while performing useful work that could be appealed to as its purpose. Some affordances and constraints for science and philosophy that result from the clockwork model are also discussed.

Keywords final causes; *machina mundi*; *perpetuum mobile*: scientific method; Scientific Revolution; worldview

McLaughlin, Peter. 2023. "Final Causes and the Clockwork Universe: The Mechanistic Worldview" In *Kosmos. Vom Umgang mit der Welt zwischen Ausdruck und Ordnung*, edited by Peter König and Oliver Schlaudt, 215–236. Heidelberg: Heidelberg University Publishing. https://doi.org/10.17885/heiup.857.c15258

What, I love, I sue, I seek a wife–
A woman, that is like a German clock
Still a-repairing, ever out of frame,
And never going aright, being a watch,
But being watch'd that it may still go right!

Shakespeare, Love's Labours Lost, 3.1

1 Introduction

There is a traditional, fairly straightforward story told about the origin of a mechanistic view of the world as a giant clockwork in the early modern period and the transformation of a traditional, finite, meaning-laden cosmos into an unlimited purposeless mechanistic universe. This development involved changes in ideas of causality: the rise of efficient causes and the decline of final causes in explanations of the world system. To understand this narrative, we begin with Aristotle's classical analysis of four contributing factors to a satisfactory explanation. We can take the simple formulation of this analysis from Aristotle's treatise on the generation of animals:

> There are four causes [*aitiai*]: (1) that for the sake of which [*heneka*], the end [*telos*], (2) the definition [*logos*] of the essence [*ousia*] (and these two we may regard as pretty much one and the same) (3) the matter [*hylê*] and (4) that from which comes the beginning [*archê*] of the motion. (Aristotle 1942, 1,1, 715a4–6)

A change, an event, or a thing is explained in terms very reminiscent of the analysis of human productive activity because nature is conceived of as productive—not so much the product of a divine artisan but as itself productive, though this can easily be turned around. In embryological development, but also in house-building, the *form* or 'essence' of the outcome is the *goal* of the process of development or production. The questions, "What?" and "For the sake of what?" seem to have the same answer: the animal, the house. But the two aspects can be analytically distinguished—perhaps against the will of Aristotle, who tended to view them as basically the same.

In the course of time Aristotle's analysis was codified and to some extent denaturalized by Christian Aristotelianism in a doctrine of four *kinds* of causes: *causa efficiens, causa materialis, causa formalis,* and *causa finalis*. Each of the aspects of explanation is viewed as a contributing cause: the force or the actions of the artisan used to make the change or the product is a contributing cause; similarly, the thing worked upon or the material used to make something is a contributing cause; the same holds for the nature of the product or the form of the object as well as the end or the purpose of the result.

Medieval Christianity and Renaissance Neoplatonism turned Aristotle's non-intentional (or at least submental) final and formal causes into mental representations or ideas in the mind of a divine artisan. When the divine artisan of seventeenth century Europe rolled up his sleeves and set to work, he generally had two things in mind: a purpose or function that the created thing was to serve and the form or structure that it had to have in order to serve that function or purpose. Since both of these ideal causes were called *design* in seventeenth century England, it is often not completely clear in so-called 'arguments from design' whether it is the formal or the final cause that is being appealed to. It was possible to explain the harmony and complexity of a system by appeal to a formal cause in the mind of the Creator without specifying what his intentions might have been when that idea was implemented.

Early representatives of modern science banned final causes from the explanation of nature. Francis Bacon famously rejected final causes altogether as barren of products.[1] Descartes and Hobbes joined him in this rejection. Descartes—somewhat disingenuously—pleaded for humility about final causes: we should not, he claimed, presume ourselves to be the confidants of God's intentions, and thus we should avoid all speculation about final causes. The material world, is not to be viewed as a means to any particular end:[2]

> And so finally concerning natural things, we shall not undertake any reasonings from the end which God or nature set himself in creating these things, [and we shall entirely reject from our philosophy the search for final causes] because we ought not to presume so much of ourselves as to think that we are the confidants of his intentions.

As with any established narrative, there is also often a revisionist narrative attached to this one. The major revisionist story about final causes points out that the next generation after Descartes revived final causes with a vengeance. Robert Boyle chided the Cartesians for acknowledging God but giving his intentions no place in their explanation of his creation:

> For there are some things in nature so curiously contrived, and so exquisitely fitted for certain operations and uses, that it seems little less than blindness in him, that acknowledges, with the Cartesians, a most wise Author of things, not to conclude, that […] they were designed for this use.
> (Boyle [1688] 2000, 403)

---

[1] *De augmentis scientiarum* 3.5: "nam causarum finalium inquisitio sterilis est et tanquam virgo Deum consecrata, nihil parit" (Bacon [1623] 1858, 571). Thomas Hobbes agrees: "A final cause has no place but in such things as have sense and will; and this also I shall prove hereafter to be an efficient cause" (*Hobbes 1656*, Ch. 10.7).

[2] Descartes [1644] 1905, 15–16.The clause in square brackets was added in the French edition, but Descartes says much the same in Latin in the *Meditations 4.6.*

Isaac Newton in the generation after Boyle even seems to have thought that assessing God's intentions was the point of doing physics in the first place, and he was always on the lookout for possible indications of God's intentions that might be drawn from his creation. He definitely believed that drawing inferences about God from empirical phenomena "does certainly belong to natural philosophy." (Newton [1687] 1999, 546) And, another generation later, Christian Wolff made a special science out of the study of such intentions—thereby coining the term *teleology* and introducing it into philosophy. Following Wolff, Pieter van Musschenbroek, one of the leading early Newtonians on the continent, incorporated the search for final causes under Wolff's heading *teleology* into his own version of Newton's "rules of philosophizing" in his widely used textbook on natural philosophy, published in Latin as *Elementa physicae* in 1734 and then translated into Dutch, French, English, and German, putting its stamp on two generations of university students all across Europe. The students learned that the search for final causes was an essential part of Newtonian philosophy—thus conferring Newtonian orthodoxy on the countless physico-theologies of the mid-eighteenth century.

Thus, the fate of final causes in the early modern period seems to be somewhat more complicated than some narratives have allowed. In fact, the notion of the clockwork universe common in the early modern period might indicate that final causes were common. Clocks and other machines, it would seem, are defined by their functions or goals whether as a screw driver or a flour mill. Hans Jonas for instance, sees clocks as prototypically teleological:

> The concept of time measurement, for example, was the generative cause of the clock, and the clock is totally defined by its end. It is literally its *raison d'etre*. Thus it 'has' this purpose truly as a determination of its essence. (Jonas 1984, 52)

However, most historians of technology would dispute this. The world machine or the clockwork universe was not defined by a final cause of creation. There is an important truth in the traditional narrative that is independent of the rise and fall of teleology in the eighteenth and nineteenth centuries.

In the twentieth century historians of science characterized the period leading up to and including the Scientific Revolution of the seventeenth century as a "mechanization of the world picture."[3] This mechanization involved two different strands of development in the science of nature: the application of mathematics to physical questions involving motion and the conceptualization of the world system as a machine. Each form of mechanization could appeal to a medieval tradition: the

---

[3] See especially Annaliese Maier (1938) *Die Mechanisierung des Weltbildes im 17. Jahrhundert* and E. J. Dijksterhuis (1950) *De Mechanisering van het wereldbeeld.*

de motu tradition of writings on kinetics and the *de ponderis* tradition of writings on statics.[4] Each of these traditions found a continuation in the development of physics in the early modern period. The first took what could be called the "high road" to celestial mechanics in a tradition from Copernicus to Kepler, Galileo, Descartes, and Newton—culminating at the end of the eighteenth century in Laplace. The second took the "low road" to terrestrial mechanics from Guidobaldo del Monte and Simon Stevin to Galileo, Descartes, and Huygens—culminating towards the end of the eighteenth century in Lagrange. Both these traditions come together in the notion of the *machina mundi,* the clockwork universe, a notion championed by almost every well-known philosopher and scientist between Descartes and Kant.[5]

But what is meant in the early modern period by comparing the world to a machine? What kind of machine was the *machina* that served as a model of the world and everything in it? A more precise determination of what exactly was meant would seem to have important consequences for the concept of nature and of the scientific knowledge of nature involved.

The characterization the world as a *machine* has a long history going back at least to Lucretius (first century BCE), who speaks of the "moles et machina mundi." And in a Latin paraphrase/commentary on Plato's *Timaeus* (ca. 320 CE) the fourth century scholar Calcidius renders Plato's *soma cosmou* ("body of the world") as *machina mundi* (Mittelstraß 1988; Fabbri 2011). But such occasional poetic dactyls and translation metaphors do not anchor a worldview, and what various authors through the years have meant by a "machine" seems to have changed over the course of time. Vitruvius (1931, 10.1.1) classically defined a machine as a "coherent combination of materials [presumably wooden] most capable of moving loads," but he often seemed to be most interested in the wooden structures themselves that supported the cranes; furthermore, his notion of machine apparently did not much influence medieval usage (Popplow 2007, 55). The prototypical machine of Antiquity is a siege tower or some other kind of scaffolding, from which, for instance, the *deus ex machina* of the theater can descend upon the stage. In any case, even though a siege tower may in fact have wheels (and thus be moveable) or have a crane (and thus be able to move things), the aspect of motion was secondary. The occasional uses of *machina* to denote the body of the world or the body of an organism through the Middle Ages tend to evoke a *structure* as the model for whatever system is being described: Albertus Magnus considered the

---

[4] See Clagett *1959*. The *de motu* tradition included writings with titles like *De motu* (John of Holland), *Tractatus de motu* (Michel Varro), *Liber de motu* (Gerard of Brussels), and *De motibus naturalibus* (Richard Swineshead). The *de ponderis* tradition included titles like *De ponderoso et levi* (Pseudo-Euclid), *De ratione ponderis* (Jordanus de Nemore), *Commentum in librum de ponderis* (Anon.), *De ponderibus* (Blasius of Parma), and *De aequali ad pondus* (Hugh of Sienna).

[5] The clock metaphor is of course much older than Descartes; for numerous earlier examples see Mayr 1986, chap. 2 and 3, and Laudan 1966.

heart to be a “principle,” upon which “the entire machinery of the body (*machina corporis*) is constructed *like a house on its foundation*, and from which all the members first receive life.”[6]

However, the wooden structures and scaffolds of antiquity and the Middle Ages were not the machines that figure in modern science and its philosophy when models of the world were introduced—though they were still used as visualizations of scientific *methods* for acquiring knowledge about the world. In one particularly vivid presentation in the Preface to the *Novum Organum* (1620) Francis Bacon appeals to the machinery used to transport the Vatican obelisk as a model for technical instruments for investigating nature in science, where “the business is to be accomplished as it were by machines”[7] (**Fig. 1**). While the Vitruvian architect’s machine, a wooden scaffolding or crane, could be used to conceptualize the science of nature, nature itself in the sixteenth to eighteenth centuries was modeled on a different kind of machine: In the Renaissance, as Popplow has shown in a number of studies, motion becomes central to the conceptualization of the machine that represents the system of the world. The stratified levels of world pictures become moving spheres of the heavens.

2 What Kind of Machine is the World Machine?

The early modern version of the *machina mundi* is no longer static. Nicholas Copernicus in the introduction to his *De Revolutionibus* (1543) speaks of a “machina mundi” while discussing the motions of the planets; John Hales in his *Discourse of the Common Weal of this Realm of England* (1549) adds motion to the *balance* of trade by viewing the English economy as a machine: “As in a clock there be many wheels, yet the first wheel being stirred, it drives the next, and that the third, till the last moves the instruments that strike the clock.”[8] And though, in spite of persistent anti-Cartesian rumors, Gomez Pereira did not in fact speak of an “animal machine” in *Antoniana Margarita* (1554) when denying that animals have a soul and viewing them as (moving) deterministic systems, his “objector” Michael de Palacios did indeed use the terms *machina mundialis* and *mundana machina*. But animals are called ‘machines’ only in the later report by Pierre Bayle in his *Dictionnaire*.[9]

From these early sources onward into the eighteenth century, the world machine or the animal machine or the societal machine is no longer a scaffold or siege tower. If

---

[6] Albertus Magnus *2008* (emphasis added). See Popplow 2007.

[7] *Bacon [1620] 1858*, Preface: “res veluti per machinas conficiatur.”

[8] Copernicus [1543] 1984, 5; Hales 1893 (written 1549, first published 1581), 98.

[9] Bayle *1740, Bd 3*: “Pereira.” Many (especially anti-Cartesian) sources attribute the term “animal machine” to Pereira himself.

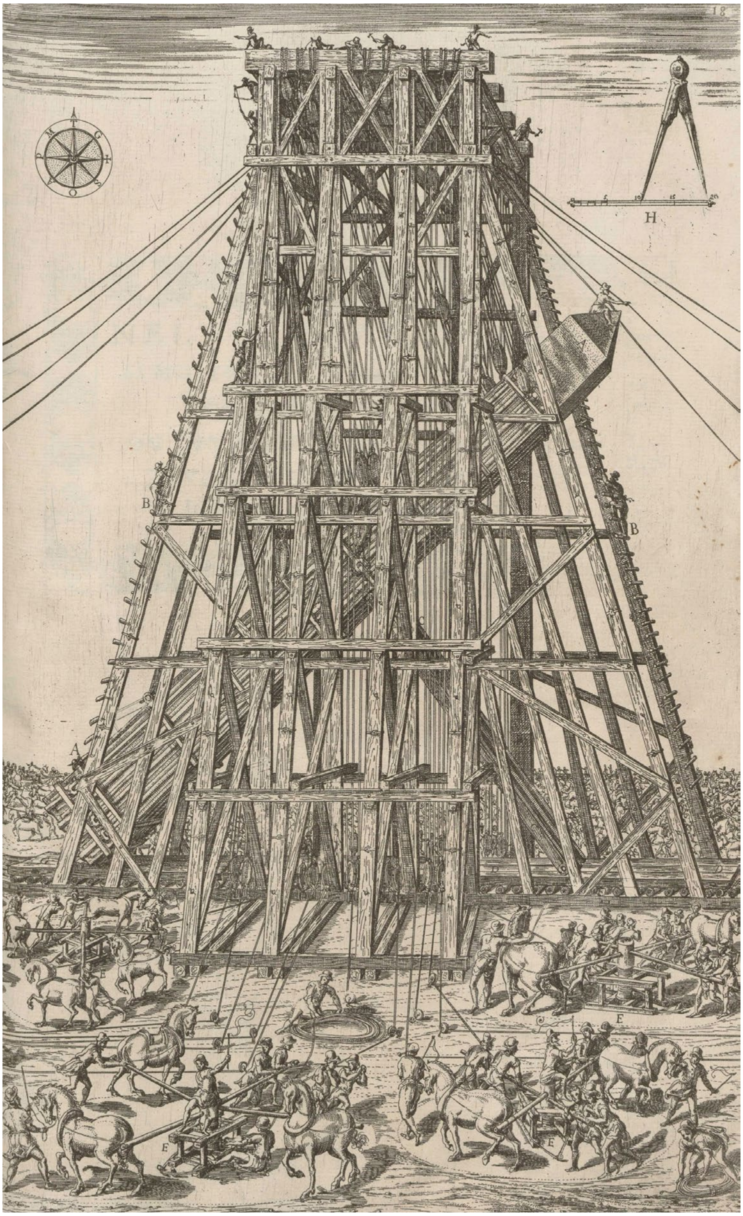

Figure 1 Classical *machina*. For Bacon a model for science not nature. See Fontana 1590.

we ask any philosopher or scientist of the early modern period, we get the same answer: the subject matter of science is like a *clock*. A clock, however, as pointed out above, is not primarily a device for telling the time. This is something that more or less all historians of technology agree about—even though the Latin *horologium* was used for both mechanical clocks and sundials. The devices avidly collected by European princes or erected at great expense for representational purposes on the cathedrals and town halls of late medieval towns were complicated devices with numerous moving parts and figures, displaying planets, signs of the Zodiac, and many other things, including scenes from the life of the saints. They also generally had an index that pointed to the hours.[10] Only in the later sixteenth century did they regularly acquire a minute hand; and only in the later seventeenth century did the time lost or gained each day sink under seven minutes. The town clocks were notoriously undependable as timekeepers and had to be reset almost every day. For this purpose, a sundial was used. A town clock needed someone to tend it and reset it every day: a governor.[11] In a late medieval town, when the mayor bought a clock for the town hall, he often hired the clockmaker to service and tend the clock. And even the fine tabletop devices made by the most skilled German craftsmen were—as Shakespeare reminds us—notoriously in need of supervision. The time-telling property of these devices could even serve as a model of waywardness.

What the natural philosophers of the seventeenth and eighteenth centuries mean when they speak of the world as a clock or of a clockwork universe is precisely the clock*work,* the mechanism of the clock itself—which means that the clock is a special kind of machine and we are back to where we started (**Fig. 2**).

If we ask not historically what a clock was taken to be, but systematically what such a complex machine is, we may get a hint at the answer. According to a standard analysis of complex machines, introduced by Karl Marx and generally accepted in history of technology, any complicated piece of machinery can be analyzed into three basic parts with a view to three basic functions: a motor or power source, a transmission mechanism, and some kind of application tool (Marx 1972, 393-394).

> All fully developed machinery consists of three essentially different parts, the *motor mechanism*, the *transmitting mechanism*, and finally the *tool* or working machine. The motor mechanism is that which puts the whole in motion.

---

[10] See White 1962; Mayr 1986, 41–42; and Cipolla 1970. See also the essays in Maurice and Mayr 1980.

[11] Gélis 1949, 48: "The office of the governor of the clock was not a sinecure. Often the governor had to wind up the clock twice a day and he therefore had to climb twice a day to the top of the clock tower; he had to grease the machine very frequently, because the gears were not so smoothly and precisely constructed; finally he had to reset the hand (or the hands) of the clock almost every time it was wound up, because the clock lost or gained much time in the course of half a day." See also Freudenthal 1986.

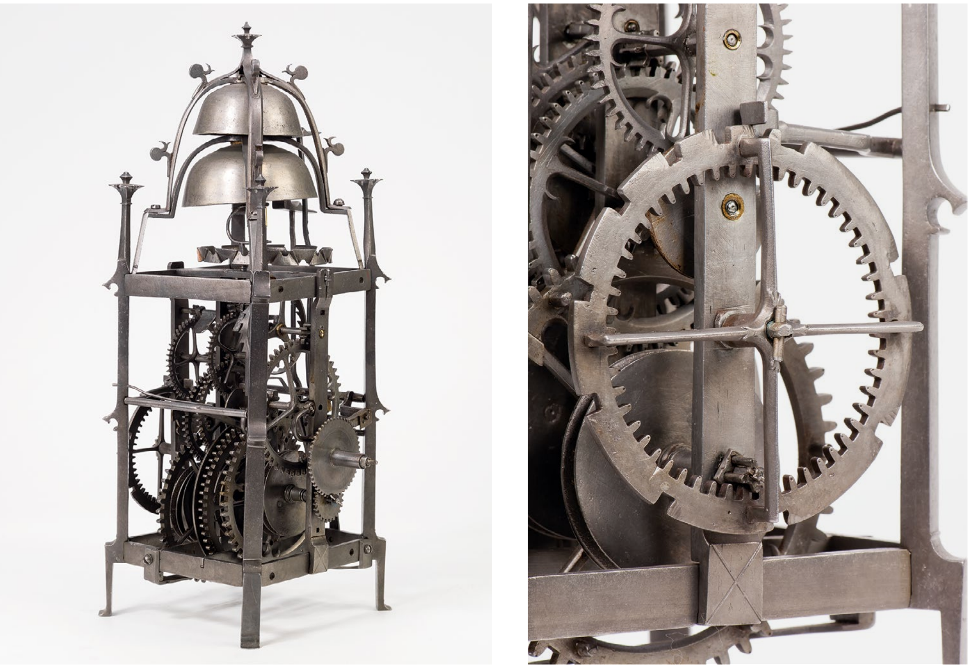

Figure 2 Clockwork.

> […] The transmitting mechanism, composed of flywheels, shafting, toothed wheel, pulleys, straps, ropes, bands, pinions, and gearing of the most varied kinds regulates the motion, changes its form where necessary, […] The tool or working machine is that part of the machinery with which the industrial revolution of the 18th century started.

As can be seen in **Figure 3**, a mill is driven by a water wheel, which is turned either by the weight (overshot wheel) or by the impulse (undershot wheel) of water. The rotational motion of the wheel is passed on by a transmission mechanism composed of gears or belts and can be transformed in speed or direction. Finally, the transformed motion is imparted to a grindstone or a hammer or some other tool, where it does its work. The Industrial Revolution of the later eighteenth and early nineteenth centuries depended on the great innovations in the area of tool machines and on the refinement of a universal motor, the steam engine; both of these came too late to be the model for the mechanism of the early modern period. The transmission machine, on the other hand, had been undergoing systematic development and progressive improvement ever since the fourteenth century. The clockwork is, so to speak, the archetype of the transmission machine. The task of the technician in building a clockwork is to master the *form* of motion. One form of (mechanical) motion is to be transformed

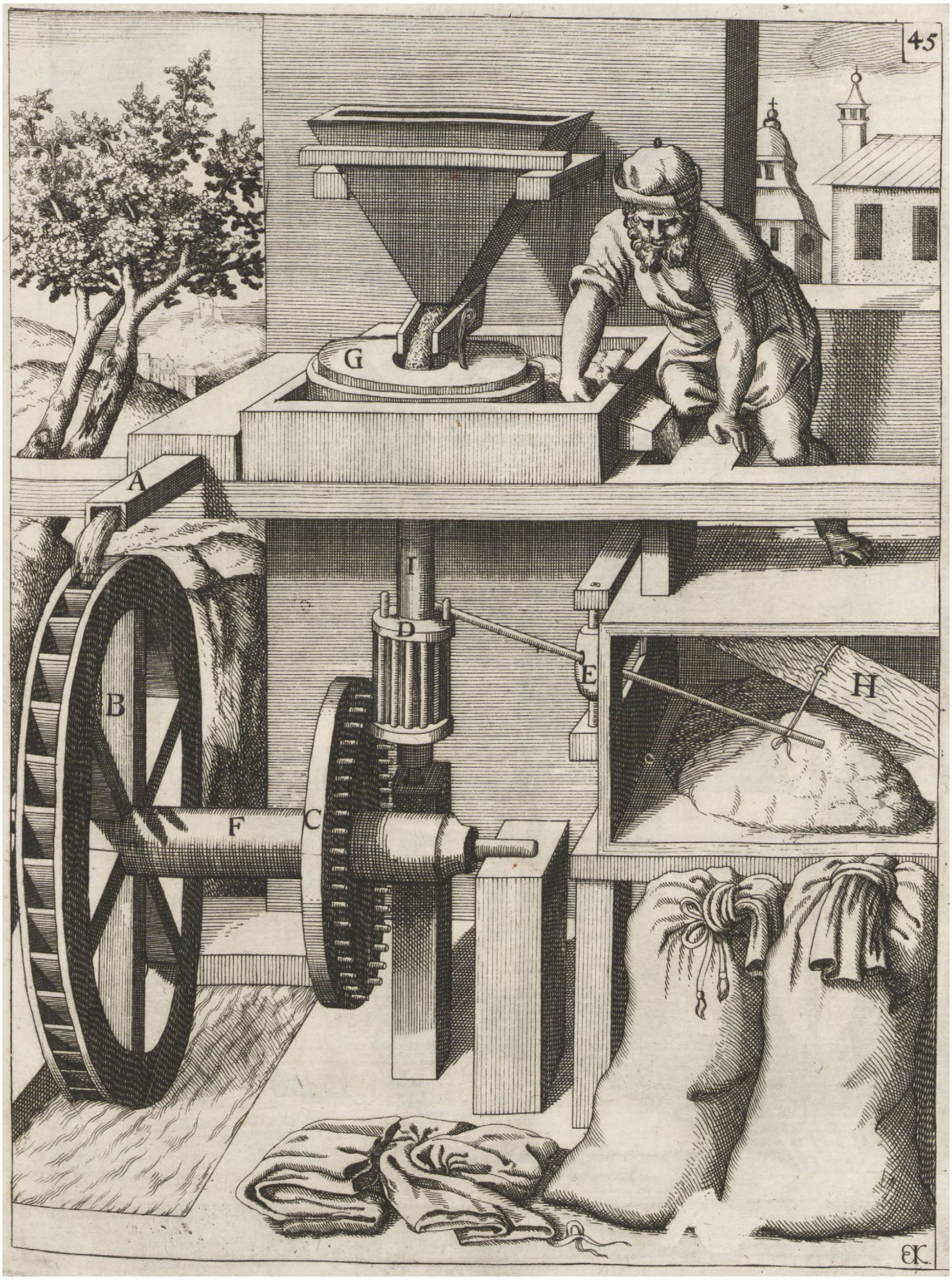

Figure 3 Overshot waterwheel with gearing mechanism, Böckler 1661, plate 45.

into another (in principle arbitrary) form of motion. The artisan had to arrange his gears, wheels, and belts so that the (interrupted) motion of fall of a weight produced various motions, which could then be imparted to figures, bells, and hammers. The escapement mechanism, invented before the middle of the fourteenth century, allowed the falling motion of a weight to be transformed into the fairly uniform rotation of a gear mechanism.[12] The figures attached to the clockwork mechanism should however not be viewed as tools, since they do not actually do any work: they merely *represent* by their motions other motions, say, the motions of the planets or the course of time. The *product* of this machine can at best be interpreted somewhat anachronistically as information: the motion of the machine provides information about the time, the season—and perhaps vicariously about the wealth and grandeur of its sponsor. The important point is that the machine that represents the material universe is not something like a water-driven mill that grinds flour or weaves cloth. The clockwork universe manufactures no goods; it performs no useful work. The clock that serves as a model of the world is a transmission machine that is running idle. The clockwork universe thus does not do anything that could be considered its goal.

The character of the world machine as a pure transmission machine is expressed very clearly in the philosophy of Descartes. In Descartes' system of the world as presented in the *Principles of Philosophy* (1644), there is a first impulse that comes from outside the material world (that is, from God); this original impulse is transferred without loss in the material interactions of bodies (Descartes condones only impact), whereby the aggregate quantity of motion is always conserved.

> God [...] in the beginning created matter along with motion and rest, and now solely by his ordinary concourse conserves as much motion and rest in this whole as he put there at that time [...] Thus it follows that it is most consonant with reason to think that from the mere fact that God moved the parts of matter in various ways when he first created them and that he conserves all this matter in completely the same mode and in the same proportion as he first created it, he also conserves as much motion in it.

Thus, Descartes' clockwork world is an ideal transmission machine that operates without any loss or friction. No motion is lost (and of course none is gained) in individual interactions. Therefore, the original impulse at the creation is conserved and no more

---

[12] See Cipolla 1970; Mayr 1986; Freudenthal 1986. This does not mean that the *entire* fall of a weight was therefore conceptualized as accelerated motion—although it might have been possible to learn this by studying the mechanism. In any case, since the fall of the weight is in fact constantly interrupted by the escapement mechanism, it is only the beginning of fall that need be seen as an acceleration.

external input is required for the motion of the clockwork. However, the clockwork universe also produces nothing. There is no tool machine attached to this particular transmission mechanism. The artisan God who created the world apparently did not create it in order to manufacture anything. The world machine was not intended to grind flour or weave cloth. Thus, the ideal transmission machine becomes the prototype of a conservative or dynamically isolated system. To the extent that the material world is a clockwork, it stays the same insofar as it retains the same amount of matter and motion or force. The conservation of matter and motion comes to define the subject matter of physics. The world is a dynamically closed system, but the perspective is different: less emphasis on boundaries or limits; more emphasis on identity of the system and conservation of quantities within it. One further consequence relates to the size (limits) of the system of the world: If conservation laws for the system of matter are to have empirical meaning, the world may not be actually infinite. Any finite loss or gain of matter or motion in interactions would be compatible with conservation of mass and motion in an infinite universe. In that case, the conservation principles would not constrain physical interactions in the world. This explains Descartes' otherwise strange insistence that the universe is not infinite but merely *indefinitely* great.

The aspect of the *machina mundi* as a boundless, dynamically closed system was taken up by Leibniz, who linked conservation laws and conservative systems to the exclusion of a *perpetuum mobile*. Leibniz distinguished two different types of *perpetuum mobile*: a *physical* perpetual motion and a *mechanical* perpetual motion.

> We can say therefore that there is a physical perpetual motion, as would be the case of a perfectly free pendulum; but that pendulum will never go beyond the original height, and it will not even reach that height if it brings about or produces the least effect in its path, or if it overcomes the least obstacle; otherwise that would be a mechanical perpetual motion.
> (Leibniz [1692] 1973, 110)

For Leibniz the world system is a physical *perpetuum mobile*, a conservative system that does nothing but continue to run. A perfect (friction-free) transmission machine preserves the original motion without loss and never runs down. In contrast, the *perpetuum mobile* that inventors had always sought is a *mechanical* perpetual motion—a machine that continues to run while at the same time performing real, useful work. The physical *perpetuum mobile* then comes to define the system to which physical laws apply; the mechanical *perpetuum mobile* comes to be an illustration of the absurd. In a worldview like that of Leibniz, the *machina mundi* performs no work; it has no tool machine attached to it. It is not there in order to make anything; it is just there to run: consequently, it has no final cause that determines it, and Descartes was right to refuse to ask about God's intentions.

3 Consequences of the Machine Metaphor

If nature is a machine, that is, if the subject of natural scientific knowledge is to be conceptualized as a machine, then there will be consequences for concept formation in science and for the philosophical analysis of this concept formation. Some of the major further consequences can be classified in three problem complexes: 1) the relation of natural and forced (mechanical) motion, 2) the conflicting further specifications of the world machine that could be made from this common starting point, and 3) some constraints on intellectual horizons that are determined by the specific kind of machine that serves as a model.

3.1 Equivalence of Forced and Natural Motion

It is not only the output side of the *machina mundi* that is affected by its nature as a transmission mechanism: there are also consequences for the input side. Aristotelian philosophy of nature had distinguished sharply between the natural motion, say, of a falling object and the forced motion of a projectile thrown or a wagon drawn. What makes the conception of nature as a machine a specifically *modern* concept is the implied equation of natural and forced motion. If nature is a machine, then natural motion is mechanical and mechanical motion is natural. Nature is not violated by forced motion but rather displayed in its pure form. The transition to this new position was sometimes proclaimed as a radical innovation, but sometimes also just concealed in a reinterpretation of Aristotle.

Francis Bacon took the first route: in mechanics, nature is compelled to show its laws in a definite form. Bacon's famous aphorism, that Nature to be conquered must be obeyed, also implies that, wherever we have in fact successfully commanded nature, we must have actually been obeying its laws:

> Human knowledge and human power meet in one; for where the cause is not known the effect cannot be produced. Nature to be conquered must be obeyed; and that which in contemplation is as the cause is in operation as the rule. (*Bacon [1620] 1858,* §3)

Thus, if we want to know what Nature's laws are, we should investigate experimentally what we can force Nature to do by means of our technology.

The second route was taken by many humanists: increasingly in the sixteenth century, the Aristotelian term for forced motion—*para physin*—was interpreted and translated as "praeter naturam" (beyond nature) instead of as "contra naturam" (contrary to nature), thus blunting the opposition between nature and art.[13] At the beginning of the mechanization of the world picture we find statics, the study of the simple machines, from which more complex machines could be constructed; statics was not only the art of outwitting nature by means of machines to force artificial motions upon it, it was also the mathematical science of forces in equilibrium (cf. Dijksterhuis 1956, 360; Westfall 1971, 3). Originally carried out on the example of the balance, the lever, and later—with Stevin and Galileo—also on the example of the inclined plane, practical mechanical problems could be reduced to pure geometry—and of course empirical knowledge of materials. The complex interaction of mechanics and mathematics already developed in statics or the science of weights was to be transferred to the study of the motions of natural bodies.

As a practical art, statics applied to forced motions—how to use machines to make things move to places they would not naturally have moved to. But as a mathematical science, it applied only to situations in which forces were in equilibrium, and thus no motions occurred. The mathematical science that actually dealt with motions—the kinematics of celestial bodies—applied to the motions of nonmaterial or at least nonearthly entities. The transfer of mathematical techniques between these two areas had to be legitimated. Nonetheless, the astrarium or orrery displays the motions of the planets by means of machinery that is driven by the fall motion of a material body.

Just as on the output side, the transmitted motion can be applied to basically any purpose, so, too, on the input side, it does not really matter to the transmission machine where the motion to be transmitted comes from: whether the input force is natural or artificial. Whether the motor or power machine is a water wheel driven by naturally falling water or a turnstile drawn by humans or oxen in forced motion, the transmitted motion is the same. A transmission machine, so to speak, does not care whether the motion that it is transmitting is originally natural or forced. The difference in the source of power disappears in the transfer. Falling water that moves naturally can be replaced by a laborer who turns a treadmill. Figure 4 shows a man and a woman, who by turning a treadmill raise water, which then falls and turns a water wheel (De Strada 1617–18). This is the technical transformation of a forced motion into a natural one (**Fig. 4**).

> This treadmill and water ladle, which is treaded by two people who brace themselves on board *A*, raises the water to a height by its buckets and pours it into the tub *B*. From tub *B* the water falls through canal *C* onto the water-wheel *D* so as evenly to drive a mill (as can be seen) and subsequently flows into *E* as sufficiently shown in the figure.

---

[13] See especially Tomeo's translation of Aristotle's *Mechanical Problems (Aristotle 1525).*

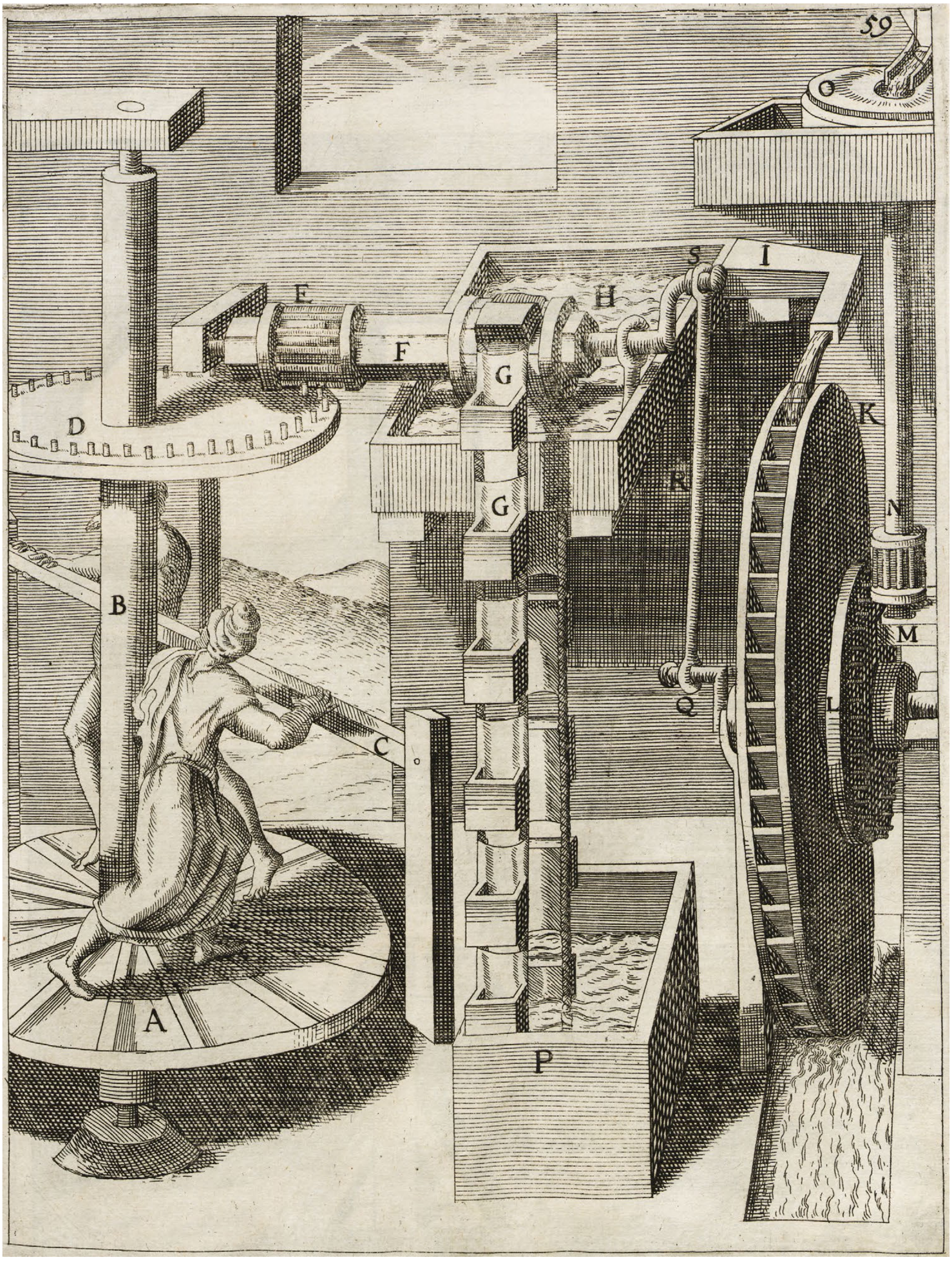

Figure 4 Transformation of forced motion into natural motion. Böckler 1661, plate 59.

This particular device was said to be of use in delivering a steady source of power, but it may actually have been more allegorical than practical. It shows that by the beginning of the seventeenth century, technical mechanics had in practice overcome the distinction between forced and natural motion that still plagued theoretical mechanics, which had not yet been able successfully to perform the abstraction in theory from the differences in motions that technology had already implemented in reality.

3.2 Common Basis for Differing Machine Concepts

Whereas practically all modern thinkers were agreed that the world is a machine or a clockwork, nonetheless the intellectual history of the seventeenth and eighteenth centuries presents us with a series of quarrels about what it means to be a clockwork. Perhaps the most important function of the clockwork metaphor was to provide the common framework that made it possible to present different views about the nature and methods of scientific knowledge. I shall illustrate briefly three dimensions on which diametrically opposing positions could be articulated.

a) Both rationalists and empiricists could view the world as a machine and use this comparison to draw epistemological conclusions. Since we explain the phenomena displayed by a material system that we study by reducing them to the properties and interactions of the parts of the system—so the empiricist can say—we have to dissect the system into its parts and examine them carefully in order to learn what their properties actually are. If I want to know how a clock really functions, I open it up and look at how it is actually constructed.

The rationalists have taken the position that we cannot actually open nature's clock. From Descartes to Einstein, they have compared the world to a clock that cannot be opened up. We are obliged to form hypotheses on the basis of observation and experiment with the motions of the hands and figures of the clock about the *kinds* of mechanisms that might be able to produce the phenomena to be explained. The truth of such hypotheses does not consist in picturing the real individual mechanism, which is in principle inaccessible, but rather in constructively simulating the phenomena, that is, in producing a functional equivalent of the system to be explained. In the classical formulation given by Descartes in the *Principles of Philosophy,* we read:[14]

---

[14] Descartes [1644], part IV, §204. Cf. Infeld and Einstein 1961, 31: "In our endeavor to understand reality we are somewhat like a man trying to understand the mechanism of a closed watch. He sees the face and the moving hands, even hears its ticking, but he has no way of opening the case. If he is ingenious, he may form some picture of the mechanism which could be responsible for all the things he observes, but he may never be quite sure his picture is the only one which could explain his observations. He will never be able to compare his picture with the real mechanism and he cannot even imagine the possibility or the meaning of such a comparison."

> For just as the same artisan can make two clocks which indicate the hours equally well and are exactly similar externally, but are internally composed of an entirely dissimilar combination of small wheels: so there is no doubt that the greatest Artificer of things could have made all those things which we see in many diverse ways.

This metaphor was pursued by many others, and after Christiaan Huygens' invention of the spring-driven watch, the alternative between weight-driven and spring-driven clocks determined the metaphor. In the classical presentation of the empiricist position, Newton's editor Roger Cotes wrote in his preface to the first edition of the *Principia*:

> The same motion of the hour hand in a clock may be occasioned either by a weight hung, or a spring shut up within. But if a certain clock should be really moved with a weight, we would laugh at a man that would suppose it moved by a spring, and from that principle, suddenly taken up without further examination, should go about to explain the motion of the index; for certainly the way he ought to have taken would have been actually to look into the inward parts of the machine, that he might find the true principle of the proposed motion. (Newton [1687] 1999, xxvii–xxviii)

In this view, science strives to determine how a particular individual system is actually constructed. One cannot merely hypothesize about the internal structure; it is necessary to open the clock and observe the actual conformation of the wheels, weights, or springs. The goal is not to explain how to make a system of the same kind, but to explain how this particular system itself actually came to be.

b) The mechanistic view of nature is in a certain sense theologically neutral. Both Deists or materialists (who allowed God no *current* role in the explanation of natural processes) and theists (who countenanced the regular intervention of God in nature) were able to develop their differing positions on the example of the clock. The best example of this is the argument between Leibniz and Newton's spokesman Clarke carried out in letters to the Princess of Wales. Leibniz saw the world as an ideal precision watch that, once created, functioned perfectly without supervision or repair: there is no *physical* reason why God should intervene in the world once it is created—though there may be *moral* reasons connected with salvation and revelation.

Newton and Clarke, on the other hand, viewed the world as a real clock, that is, one that did not actually run true and therefore occasionally—or even regularly—needed God's "inspection and government" in order to function regularly. The actual motion of the hands of a tower clock is for the most part due to the inner mechanism, but it is also partly determined by the intervention of the 'governor' of the clock. Thus, Leibniz and Clarke were in agreement that the world was something like a clock, but as soon as the notion of a clock became more concrete, they disagreed on the nature of that clock. In this particular case, they were even careful to use different terms in order to distinguish the two different models. Leibniz calls his model "montre" (which Clarke translated as *watch*). Clarke calls his model a "clock" (translated into French as *horloge*).[15]

c) Even the reductionism seemingly implied by the notion of the clockwork world is not unambiguous. A machine can be taken apart—in thought or in reality—and then be put back together. But it is not clear from the start how far you can or should dissect the world. Since a clockmaker who takes apart a clock does not normally then continue and take apart the gears and wheels themselves, it is not unequivocally clear whether the process of dissection is supposed to have a natural endpoint or not—whether it can be continued indefinitely at ever lower levels. The clock metaphor presupposes only that every system is to be explained by the properties and interactions of its parts; it does not determine whether or not every part of a system is itself to be conceived of as a system as well. Newton, for instance, believed that there were ultimate particles of matter, atoms, which were themselves not systems and thus could perhaps be inspected but not dissected. Ultimate particles cannot be *explained* by analysis: they may be described, but not dissected. Leibniz, on the other hand, considered everything to be a system, so that no matter how far you subdivide a body you will never find simple parts: explanation at all levels has basically the same, analytic-synthetic form.

But whether the corpuscles were conceived of as atoms or as indefinitely divisible systems, still the conceptualization of the properties of the particles from which the clockwork world was to be explained was not unambiguous. It was still an open question what properties or kinds of properties could be ascribed to the particles in order to explain the system. Up to the end of the seventeenth century, it was taken as self-evident that only "mechanical" properties should be introduced—although there were various, differing lists of mechanical or primary properties.

These examples should have made it clear that the conception of the clockwork world has further consequences for the image of science, scientific knowledge, and the subject matter of science only when it is further specified what exactly is meant by the clock metaphor.

---

[15] See Clarke and Leibniz 1717; and Freudenthal 1986, chap. 3.

3.3 Horizons and Their Constraints

The fact that the material world is conceptualized as a clockwork also puts some constraints on theory formation. This was pointed out especially in the work of the economist-historian Henryk Grossmann and the historian and philosopher of science Boris Hessen (Grossmann [1935, 1943] 2009; Hessen [1931] 2009.). One of the points that they emphasize in their work is that only that one particular form of motion that had been dependably mastered in technology, namely the mechanical translation embodied in the transmission machine, could be fully integrated into a system of science. Other forms of motion or, as we would say today, other forms of energy, such as thermal or electromagnetic energy, and the conversion of one of these forms into the other, could only be integrated into an experimental science after they had been technically mastered in the steam engine and the generator. According to this interpretation, it was the transmission mechanism, that is, the dependable technical mastery of mechanical forms of motion that first made a systematic study of motion and the experimental examination of theories in mechanics possible. On the other hand, the fact that only this particular area had been mastered technologically put constraints on the formation of theories that could be tested empirically in experiment. As long as nature is conceived as a machine, specifically as a mechanical transmission machine, none but mechanical forms of motion or energy are envisioned. And only these could be could be dealt with reliably in technology. Thus, the world machine could be conceived as a conservative system, allowing Descartes and Leibniz to formulate conservation laws as the foundations of physics, but these conservation laws were not general laws of the conservation of energy, but only laws of the conservation of *mechanical* energy. In cases where mechanical energy appears or disappears, Leibniz speculated about hidden inner motions (also mechanical) which were supposed to conserve mechanical motion. And there was no plausible solution to the *vis-viva* quarrel of the eighteenth century until the general physical principle of the conservation of mv^2 could be distinguished from the specifically mechanical principle of the conservation of mv *(Planck 1913)*.The development of technology in the nineteenth century changed this as nonmechanical forms of technology became more common: in particular, steam technology allowed the conversion of heat into mechanical motion. As Grossmann reformulated Hessen's thesis:

> Whereas in the machines of classical mechanics one form of mechanical motion was transformed into another form of the same mechanical motion (e.g. rectilinear motion into circular motion), the essence of the steam engine lies in the transformation of a thermal form of motion into a quite different, namely mechanical, form. (Grossmann [1938] 2009, 236)

The historical record gives some credence to these ideas, since the theoretical mastering of the various forms of energy in physics—mechanics, thermodynamics, electrodynamics—seems to have followed the steps of the initial technical mastery of these phenomena: first in mechanical technology, then in the steam engine, and then in electrical technology.

Figures

Fig. 1 Institut national d'histoire de l'art, Paris (https://bibliotheque-numerique.inha.fr/idurl/1/35317), Open Licence

Fig. 2 © Bayerisches Nationalmuseum München. Inv.-Nr. 33/122, Foto Nr. D68269, Foto Nr. D68289. Fotos: Krack, Bastian

Fig. 3–4 Sächsische Landes- und Universitätsbibliothek (SLUB) Dresden. Public Domain Mark 1.0

References

Albertus Magnus. 2008. *Questions concerning Aristotle's on Animals.* Trans. by Irven M. Resnick and Kenneth F. Kitchell, Jr. Washington, DC: Catholic University of America Press.

Aristotle. 1525. *Questiones mechanicae.* In *Opuscula nuper in lucem aedita*. Trans. by Niccolò Leonico Tomeo. Venice: n. p.

——. 1942. *De generatione animalium*, Trans. by A. L. Peck. *Loeb Classics.* Cambridge: Harvard University Press.

Bacon, Francis. [1620] 1858. "*Novum Organum.*" In *The works of Francis Bacon*, ed. by James Spedding, Robert Ellis, and Douglas D. Heath, vol. 4. London: Longmans.

———. [1623] 1858. "*De augmentis scientiarum.*" In *The works of Francis Bacon*, ed. by James Spedding, Robert Ellis, and Douglas D. Heath, vol. 1. London: Longmans.

Bayle, Pierre. 1740. *Dictionnaire historique et critique.* 5. Ausg. Amsterdam: Brunel.

Böckler, Georg Andreas. 1661. *Theatrum Machinarum Novum, Das ist: Neu-vermehrter Schauplatz der Mechanischen Künsten*. Nürnberg: Paul Fürst.

Boyle, Robert. [1688] 2000. "*A Disquisition about the Final Causes of Natural Things*" In *The Works of Robert Boyle*, ed. by Michael Hunter and Edward B. Davis, vol. 11. London: Pickering & Chatto.

Cipolla, Carlo M. 1970. *Clocks and Culture*. Harmondsworth: Penguin.

Clagett, Marshall. 1959. *The Science of Mechanics in the Middle Ages. Madison: University of Wisconsin Press.*

Clarke, Samuel, and Gottfried Wilhelm Leibniz. 1717. *A Collection of Papers, which Passed between the Late Learned Mr. Leibnitz, and Dr. Clarke, in the Years 1715 and 1716. Relating to the Principles of Natural Philosophy and Religion*. London: Knapton.

Copernicus, Nicolaus. [1543] 1984. *De revolutionibus orbium coelestium. Gesamtausgabe, vol. 2,* Hildesheim: Gerstenberg.

Descartes, René. [1644] 1905. *Principia philosophiae.* In *Œuvres*, hrsg. von Charles Adam und Paul Tannery, Band 8. Paris: Cerf.

de Strada, Jacopo. 1617/18. *Künstliche Abriss allerhand Wasser- Wind- Ross- und Handt-Mühlen*. Frankfurt: n. p.

Dijksterhuis, Eduard J. 1956. *Die Mechanisierung des Weltbildes.* Berlin: Springer.

——. 1950. *De Mechanisering van het wereldbeeld.* Amsterdam: Meulenhoff.

Fabbri, Natacha. 2011. "*Deus mechanicus and machinae mundi* in the Early Modern Period." *Historia Philosophica 9*: 75–112.

Fontana, Domenico. 1590. *Della trasportatione dell'obelisco Vaticano*. Rome: Appresso Domenico Basa.

Freudenthal, Gideon. 1986. *Atom and Individual in the Age of Newton*. Dordrecht: Reidel.

Freudenthal, Gideon, and Peter McLaughlin, eds. 2009. *The Social and Economic Roots of the Scientific Revolution. Texts by Boris Hessen and Henryk Grossmann. Boston Studies in the Philosophy of Science 278*. New York: Springer.

Gélis, Edouard. 1949. *L'horlogerie ancienne.* Paris: Grund.

Grossmann, Henryk. [1935] 2009. "The Social Foundations of the Mechanistic Philosophy and Manufacture." In *The Social and Economic Roots of the Scientific Revolution. Texts by Boris Hessen and Henryk Grossmann*, ed. by Gideon Freudenthal and Peter McLaughlin. *Boston Studies in the Philosophy of Science 278*. New York: Springer.

——. [1938] 2009. Review of G. N. Clark, *Science and Social Welfare in the Age of Newton* (1937) [*Zeitschrift für Sozialforschung* 1938]. In *The Social and Economic Roots of the Scientific Revolution. Texts by Boris Hessen and Henryk Grossmann,* ed. by Gideon Freudenthal and Peter McLaughlin. *Boston Studies in the Philosophy of Science 278*. New York: Springer.

——. [1943] 2009. "Descartes and the Social Origins of the Mechanistic Concept of theWorld." In *The Social and Economic Roots of the Scientific Revolution. Texts by Boris Hessen and Henryk Grossmann*, ed. by Gideon Freudenthal and Peter McLaughlin. *Boston Studies in the Philosophy of Science 278*. New York: Springer.

Hales, John. [1581] 1893. *Discourse of the Common Weal of this Realm of England.* Cambridge: Cambridge University Press.

Hessen, Boris. [1931] 2009. "The Social and Economic Roots of Newton's *Principia*." In *The Social and Economic Roots of the Scientific Revolution. Texts by Boris Hessen and Henryk Grossmann,* ed. by Gideon Freudenthal and Peter McLaughlin. *Boston Studies in the Philosophy of Science 278.* New York: Springer.

Hobbes, Thomas. 1656. *Elements of philosophy the first section, concerning body*. London: Crooke.

Infeld, Leon, and Albert Einstein. 1961. *The Evolution of Physics. The Growth of Ideas from Early Concepts to Relativity and Quanta*. Cambridge: Cambridge University Press.

Jonas, Hans. 1984. *The Imperative of Responsibility.* Chicago: University of Chicago Press.

Laudan, Laurens. 1966. "The Clock Metaphor and Probabilism." *Annals of Science 22*: 73–104.

Lefèvre, Wolfgang. 1978. *Naturtheorie und Produktionsweise.* Darmstadt: Luchterhand.

Leibniz, Gottfried Wilhelm. [1692] 1973. "*Dynamique.*" In *Leibniz and Dynamics*, ed. by Pierre Costabel. Paris: Hermann.

Maier, Anneliese. 1938. *Die Mechanisierung des Weltbildes im 17. Jahrhundert*. Leipzig: Meiner.

Marx, Karl. 1972. *Das Kapital, Marx-Engels-Werke,* vol. 23. Berlin: Dietz.

Maurice, Klaus, and Mayr, Otto, eds. 1980. *Die Welt als Uhr. Deutsche Uhren und Automaten 1550–1650*. Munich: Bayerisches Nationalmuseum.

Mayr, Otto. 1986. *Authority, Liberty and Automatic Machinery in Early Modern Europe*. Baltimore: Johns Hopkins University Press.

Mittelstraß, Jürgen. 1988. "Nature and science in the Renaissance." In *Metaphysics and Philosophy of Science in the Seventeenth and Eighteenth Century*, ed. by Roger. S. Woolhouse, 17–44. Dordrecht: Kluwer.

Moran, Bruce T. 1977. "Princes, Machines and the Valuation of Precision in the 16th Century." *Sudhoffs Archiv 61*: 209–228.

Newton, Isaac. [1687] 1999. *The Principia: Mathematical Principles of Natural Philosophy*. Trans. by I. Bernard Cohen and

Ann Whitman. Berkeley: University of California Press.

Pereira, Gomez. 1554. *Antoniana Margarita.* Methymnæ Campi: n.p.

Planck, Max. 1913. *Das Princip der Erhaltung der Energie*. Leipzig: Teubner.

Popplow, Marcus. 2007. "Setting the World Machine in Motion: The Meaning of *machina mundi* in the Middle Ages and the Early Modern Period." In *Mechanics and Cosmology in the Medieval and Early Modern Period*, ed. by Massimo Bucciantini and Sophie Roux, 45–70. Florence, Olschki.

Vitruvius Pollio, Marcus. 1931. *De Architectura/On Architecture.* 2 vols., Loeb Classics 251 and 280. Cambridge, MA: Harvard University Press.

Westfall, Richard. 1971. *Force in Newton's Physics*. London: Macdonald.

White, Lynn. 1962. *Medieval Technology and Social Change*. Oxford: Clarendon.