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DREBBEL'S LIVING INSTRUMENTS, HARTMANN'S MICROCOSM, AND LIBAVIUS'S THELESMOS: EPISTEMIC MACHINES BEFORE DESCARTES

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Historians of science long ago ousted a once-assumed mechanization of the world picture from its privileged place as an abrupt shift in the Scientific Revolution. On the one hand, Simon Schaffer has pointed out the continuation of non-mechanical entities in the Royal Society, and on the other, Daniel Garber has pointed out how Cartesian mechanics was not incommensurable with its predecessors.[1] If there was no sudden flicking of a 'gestalt switch' between vital and mechanized worlds, then the trading zone between them, if any existed, ought to become a key area of research.[2]

As it happens, in the early seventeenth century there was extreme excitement surrounding the area intervening precisely between vitalism and mechanism — vital machines — and in particular the inventions and related natural philosophy of the alchemist, inventor, and machine-based but non-mechanical philosopher Cornelis Drebbel (1572–1633). Drebbel's natural philosophy has never been fully analysed by a modern historian despite its impressive early modern reception. His texts appeared in twenty-seven early modern editions in Dutch, German, Latin, and French, and were read, taught, cited, and plagiarized across Europe. This is the story of Drebbel and his readers. It is also the story of how a paradigm shift did not come about suddenly through incommensurability, but was constructed gradually through purposeful re-interpretation.

This shift says as much about what was known as who was allowed to know. Daniel Garber has argued that the 'arational' argumentation observed during moments of Kuhnian shifts are not due to incommensurability but are "a kind of proxy for a deeper social struggle".[3] I would like to suggest that the social struggle here is not only between such classic opponents as academic Aristotelians and the heterodox Descartes, but between Descartes and his competing heterodox artisanal philosophers. Threats faced mechanical philosophers not only from mechanicks, who had privileged knowledge of the machines now seen as the basic components of the universe, but from chemical philosophers, who had never distinguished between artificial and natural objects, and who had long prized the role of art and technology in philosophy.[4] The recent introduction of alchemy to the academy had elevated the authority of chemical knowledge for a wide philosophical audience.[5] Although the alchemical work of practising alchemists such as Robert Boyle and Isaac Newton has now received attention, alchemy still often appears irrelevant to the historiography of non-alchemical concerns such as mechanics and the mechanical philosophy.

Such irrelevance is an artifact of a purposeful re-interpretation, which was every

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bit as much a proxy for a deeper social struggle as the struggle between orthodox Aristotelians and heterodox Cartesians. Despite the rise of the epistemic authority of mechanics, an easy alliance cannot be assumed between mechanicks and mechanical philosophers.[6] Mechanical philosophers deployed the once lowly status of mechanics to keep mechanicks in their place, even as they worked to legitimate mechanics as physics. The history of mechanical philosophers is rife with their rejection of the authority of mechanicks and even with their claims to priority for mechanical inventions.[7]

Chemistry, on the other hand, never accepted the lowly status accorded to mechanics; alchemists had always claimed for themselves the authority granted magi and philosophers, although they frequently rejected competing alchemists as charlatans.[8] Mechanical philosophers avoided the epistemic claims of alchemists by masking alchemy as mechanics. Modern historians of science run the risk of performing the same act of concealment by defining mechanical philosophy very broadly as maker's knowledge, despite the importance of makers with vitalist, qualitative, and chemical philosophies in the period.[9] As a result, the precise relationships, compromises, and negotiations between mechanics and chemistry go unstudied, masked as a generalized mechanical world view.

Due to the ongoing recognition of the importance of artisanal knowledge to the history of experiment, many historians have revealed the work of invisible technicians or uncovered implicit forms of artisanal knowledge.[10] Cornelis Drebbel, by contrast, has been concealed in plain sight. He was renowned across Europe from early in his career, both as an inventor, an alchemist and the author of a popular work of natural philosophy. In particular, he owed his fame to his ability to combine practical knowledge of mechanics, pneumatics, and alchemy in an explicit, and, according to many of his readers, innovative natural philosophy. However, Drebbel usually appears in historiography only as a mechanick, and even as evidence for a generalized mechanical culture and mathematical art of describing.[11] In other words, his invisiblity as a mechanical technician is an artifact of historiography. Despite his past fame as a physico-chemical author, he is by no means a major figure in the history of science today.[12]

Coming from a comfortable but by no means learned background of Dutch farmers, Drebbel began to rise to international prominence through his marriage to the sister of the famed artist, Hendrick Goltzius. Drebbel started his career as an engraver after designs by Goltzius and Karel van Mander, but quickly turned to the invention of clocks, pumps, and motions and the study of nature through alchemy. After the death of his widowed mother in 1604, Drebbel received a sizeable bequest. That same year he published a short work on natural philosophy in Haarlem and then went to seek his fortune as an inventor in England.[13] Within a few years, he had impressed both James I, who installed him and his inventions in Eltham Palace outside London, and Rudolf II, for whom he worked in Prague from 1610 until Rudolf's death in 1612. Drebbel returned to England and the Ordnance Office, where, under the patronage of the Duke of Buckingham and Charles I, he became Chief Engineer and continued to peddle, develop, and invent optical instruments, self-regulating furnaces, a scarlet dye, chemical techniques, refrigeratory instruments, and, most famously, his submarine, until his death in 1633.[14]

Drebbel was noted for his success as an engineer in England, but he became even better known as a writer on the Continent. His fame and authority as a philosopher grew from the invention of what he called "living instruments [*levendige Instrumenten*]" which fused alchemy, mechanics, pneumatics, and physics. Drebbel's simple, artisanal approach to what appeared to be immediate and pansophic knowledge enthralled many academic alchemists and Ramists in particular. They embraced his machine-based philosophy, including the use of "living instruments", as a direct means to studying the working of the greater world machine.

Such fans did not include Descartes. As a reader of Isaac Beeckman's journal, Descartes certainly knew of Drebbel. His correspondents Beeckman, Constantijn Huygens, Nicholas-Claude Fabri de Peiresc and Marin Mersenne all read Drebbel's *On the nature of the elements* (Peiresc even had it specially translated into French), and they also discussed Drebbel's inventions, as did Justin van Assche and Pierre Gassendi.[15] Descartes himself, as Arianna Borrelli noted, did not mention the extremely famous inventor-philosopher, although his mechanical models of life closely resembled Drebbel's inventions, and even the short and vernacular style of his natural philosophy recalled Drebbel's texts.[16] Just as Descartes set aside Aristotelian explanations while adopting Aristotelian subject matter, so too did he set Drebbel aside, although the similarities between Descartes's mechanical models of life and Drebbel's inventions were apparent to early modern writers.[17]

Complete evasion is a very effective strategy. It makes it impossible to prove that Descartes purposefully did not cite Drebbel. The avoidance of Drebbel's philosophical explanations and the re-interpretation of his subject matter as mechanical have succeeded brilliantly. The living instruments that were so famous in the seventeenth-century have been studied as primitive versions of a metric instrument — the thermoscope — which is a mechanical re-interpretation of what had been a physico-chemical object.[18]

I do not wish to revive the old debate over priority in invention of the thermometer, but to suggest that the very question and its implied view of the "living instrument" as a mechanical device were not accidental consequences of an abrupt shift to a mechanized world view, but artifacts of a purposeful re-interpretation. As a result, our inability to resolve the question of priority for this invention has not been due to an accidental failure of the historical record, but also stems from the mechanical re-interpretation of both physics and chemistry. The very question, "Who invented the thermometer?" starts with the premise that an individual set out to build a distinct object that still exists today. Yet that question cannot be resolved, since the object in question was not itself stable.[19] Drebbel did set out to build an object, and the historical record is rife with discussions of its significance, both by Drebbel himself and by a wide range of eminent natural philosophers of the time. By interpreting that object as a thermoscope, that is, a device for the measurement of heat, we have turned away from all those sources, including Drebbel himself, who did not interpret the object the same way. Through a seemingly innocent, antiquarian question, we created a failure of the record, and an entire school of machine-based but non-mechanical philosophers fell through the gap.

A new biography of this scientific object will entail the recovery of their forgotten fantasy — a single, living machine that could encapsulate, prove, and effortlessly convey universal knowledge of nature.[20] Drebbel never intended his object to be merely an instrument of measurement, but rather a moving microcosm or compendium of all natural knowledge to be observed in a glance. Contemporaries usually called this a perpetual motion, and we might term it a cosmoscope.[21] Only slowly did the thermoscope (measuring one phenomenon) emerge as an object incommensurable with the cosmoscope (displaying all phenomena). The cosmoscope cannot be understood at all in terms of today's thermometer, but for a few decades in the seventeenth century, the thermoscope still shared the cosmoscope's frame of reference. Both were employed in similar ways as philosophical centrepieces during a critical period for the rise of machine-based natural philosophy. The transformation of and oscillation between cosmoscope and thermoscope thus begs a much richer question concerning the ways quantitative mechanical philosophy intervened in an already robust, machine-based, but non-mechanical natural philosophy.

The difference between these two objects lay partly in disparate views of the ideal social organization of natural philosophy. The cosmoscope suggested a single, pansophic artisanal philosopher, who based his knowledge in his own manual construction of a working microcosm that validated all of his theories. This model entailed a close association between the body of the artisan and the content of his own natural philosophy encapsulated within his single, personal device. By contrast, the thermoscope/thermometer, as a specialized metric instrument rather than a universal demonstration, suggested a diverse range of individuals and an equally wide array of experiments. The instrument was not itself an experiment, but a tool to be used in many experiments. Different individuals might make the instrument from those who used it, noted down observations, and collated those observations. The maker of the thermometer enjoyed no philosophical authority for having constructed the instrument. That authority rested with those who knew how to collect and build systems out of the data the instrument provided and who co-ordinated a scattered range of both individuals and instruments with specialized skills. Although large-scale, differentiated projects of observation would prevail ultimately, Drebbel helped to legitimate machine-based philosophy for an earlier generation by offering an appealing, pansophic philosophy validated within a single, all-encompassing machine.

Given the impossibility of proving Descartes's evasion of Drebbel, I will instead reconstruct the machine-based philosophical horizons in which he wrote. First I will clarify the aims of Drebbel's instruments and the legitimation he offered for their epistemic abilities. The status of the instrument stemmed from a fusion of both artisanal and philosophical authority. I will then briefly point to other philosophers and artisans, besides Descartes, who deployed the instrument (with varying levels of re-interpretation) as an artisanal centrepiece for philosophical texts and a philosophical centrepiece for artisanal texts. Finally, I will analyse the reception of the instrument and the great authority it was accorded in a new discipline — academic alchemy — which prized the successful fusion of artisanality and philosophy, and in particular, the varying ways Andreas Libavius and Johann Hartmann interpreted Drebbel's work. I hope as a result to show the importance of the history of alchemy in recovering what mechanical philosophers concealed when they re-interpreted other disciplines as mechanics.

PHYSICO-CHEMICO-MECHANICAL MACHINES AND PHILOSOPHIES

I am adopting the unfamiliar term 'cosmoscope' rather than 'perpetual motion' for Drebbel's "living instrument", since perpetual motion no longer carries the range of meanings associated with it in the seventeenth century. Perpetual motion now implies an anachronistic assumption of impossibility. We also now often elide the important early-modern distinction between mechanical or mathematical perpetual motions, and physical or physico-chemical ones. As Alan Gabbey has discussed, the former were often considered impossible even in the seventeenth century, while the latter frequently were not.[22] The latter, rather than forcing nature against herself through the use of weights, springs, or other mechanical motions, drew upon natural qualities. They thus had access to the perpetual motion observed in the universe. Mechanical motions depended on the movement of dead matter through art, and thus were not linked to living, self-moving nature. Mechanical motions not only lacked natural sources of perpetual movement, but before the ascendance of mechanics, they also lacked the epistemic authority arising from a physical link to nature.[23]

The search for chemical perpetual motions was a means to investigate the source of motion in the macrocosm, and the discovery of a working chemical microcosm offered proof of understanding the macrocosm's motion. In this sense, there was no distinction between seeking the *perpetuum mobile* and the *primum mobile.* Indeed, as Drebbel wrote in his letter to King James I on the perpetual motion, he "undertook to investigate the cause of the *Primum mobile*, feeling that that was the first principle of God's work, and therefore an entry into the true knowledge of Nature". However, although he attempted to discover this motion for a long time, "the Nature of all things" let him "know the impossibility of discovering" the first motion. Indeed, his first attempt at the perpetual motion might have been a mechanical one, as his 1598 patent for a perpetually-moving clock indicates.[24] Yet then, "noting how all things have been created, nourished, and maintained through the Elements", he undertook "to investigate their Nature and effects, in which my time was not misspent, for I had noted that these were the doors to the right knowledge of things". Drebbel did not seek an arrangement of perpetually moving dead matter, but an understanding of the sources of movement and life in the entire universe.

In Drebbel's *A short treatise on the nature of the elements and how they cause wind, rain, lightning and thunder and how they can be used* (1604), he described the perpetual motion of the universe as it cycled in seasonal and diurnal weather changes and life cycles through a constant movement of the elements, starting with the creation of the world. One might interpret this natural philosophy mechanically. On one level, Drebbel discussed these elements as bodies that pressed against each other, and transformed from one state to the next (water to air, for example) at an explosive rate. Read mechanically, this text did offer innovative ideas, including laws of storms, a new theory of the winds, a rejection of the decuple rate of expansion between the elements, the idea that this rate can be as great as thousands of times and can also vary depending upon the original and resulting densities of the expanding matter, the idea that the fire of the sun and the fire found on earth are identical, and the idea of an infinite universe. However, the mechanical interpretation would result in only a partial understanding of the book. As Mersenne, who probably read the work from a mechanical perspective, wrote to Theodore Haak on 20 March 1640, "I have seen the Compendium of Physics of Cornelius Drebbel, but it does not deserve the reputation it has, being exceedingly simple".[25]

Drebbel's "Physics" gained its reputation from its chemical readers, who saw it as a far more sophisticated text than did Mersenne. When they approached the text, they noted what lay concealed within the bodies of the elements. The work of Petrus Severinus had already familiarized alchemical readers with a matter theory based on corporeal containers concealing hidden seeds.[26] Severinus had set the work of the medical theorist and occult empiricist Jean Fernel on theoretical and chemical foundations.[27] Alchemists welcomed alchemical readings of Fernel's texts, particularly Fernel's idea of a second heat found within matter and responsible for life, encouraging new explorations into the chemical bases of animal heat.[28] To them, Drebbel's discussion of the actions of heat and cold (read by mechanists as a primitive account of a thermometer) included an exploration of vital heat.

To alchemists reading *On the nature of the elements*, it was no surprise that natural philosophy could simultaneously address the mechanical interaction of corporeal containers and the vital affects of the seeds contained inside. Indeed, Drebbel openly claimed that he was not really interested in earth, air, fire, and water, but in the "growth" and "seeds" they held within them. As he said, he only referred to the "common elements as they are best known to you so that you may learn to know the rest, namely the earth, since the earth is not as simple as fire, air, and water, but it is the impure remainder so that one finds the four elementary natures completely in the earth, and their growth [*gewächs*], with which we bring our work to completion".[29] The explosive movement and interaction of the cycle of the elements was originally sparked by these contents, and the entire movement of the elements served to circulate and purify them, nourishing life and generating different types of growth.

The idea of circulating matter through a *rota elementorum*, or circle of the elements, was familiar to alchemists who attempted to create alchemical perpetual motions by trying to circulate matter through a series of states, seeking to bring hidden contents to the surface and to an active state. "Element-glasses" were also recognizable objects to alchemists, who sought to re-create and observe the sequence of Genesis within their retorts, as though in an early modern Large Hadron Collider.[30] Drebbel himself began *On the nature of the elements* with a description of the separation of the elements in Genesis, which was a frequent opening for alchemical texts.

Alchemical readers read Drebbel in light of an extensive alchemical literature. The academic alchemist Andreas Libavius, for instance, said that the books of Michael Sendivogius and Drebbel would have been nearly identical had Sendivogius not written in Latin, since both explained both universal and particular nature through the circulation and mixture of the elements.[31] Both developed an entire natural philosophy centred around the hidden food of life carried within the elements. Both thought that what they observed in the alchemical process was also what happened in the microcosm at large, recognizing no difference between the alchemical furnace and the furnace of nature.[32] The furnace of nature contained an internal calorific principle which agitated matter and drove it round in a perpetual motion.[33] The search for a perpetual motion was identical to the search for this internal fire of nature. That search began with the use of the elements to cycle matter within the alchemical furnace, just as matter was cycled in the macrocosm, in order to purify and bring the hidden contents of the elements into an active state.

The material objects to which Drebbel referred in *On the nature of the elements* further placed the text in an alchemical context. In Chapter Four, Drebbel described a demonstration of motion using a retort.[34] His alchemical readers saw this demonstration in the context of the *rota elementorum.* Drebbel suspended a retort above a vessel of water heated so that that expanding air bubbles issue from the mouth of the retort through the water (the production of wind). Once the retort cooled, the contraction of the cold (according to Drebbel) forced the water from the vessel up into the retort, higher above the level of water in the surrounding vessel. This demonstration showed how the rarefaction and condensation of air and water could move these elements praeternaturally beyond their natural levels.

Drebbel was interested in how this demonstration could explain macrocosmic meteorological cycles such as wind through pneumatic force. He did not distinguish between barometric pressure and heat (and neither did his demonstration, which was exposed to the air, rather than enclosed fully in glass like later thermoscopes). For Drebbel's mechanical readers, the arrangement of fire, retort, vessel of water, and surrounding air showing the motion of air shooting out and water being draw up into the retort was either a display of Drebbel's new theory of the wind or an extremely primitive thermoscope. For chemical readers, the corporeal motion of the air, fire and water was but the beginning. For them, the question of all movement and life in the universe lay on the inside of those *corpora* circulated through the *rota elementorum.*

Drebbel employed the motion displayed in his retort in highly sensitive small worlds and self-regulating systems of heat and cold, involving a cycling transformation of the elements through different states. For instance, his self-regulating furnace, now considered the first "feedback control device", demonstrated the role of the elements in carrying the hidden sources of nutrition sustaining life.[35] Viewed according to Drebbel's natural philosophy, both the mechanical aspects of air (size, weight, pressure) and air's hidden, chemical content (the quintessence of the air that sustained fire) played a part in Drebbel's furnace. The furnace contained a retort, partially filled with the spirit of wine and partially with mercury, which touched upon a pin, upon which lay one end of a spoon, the other end of which covered an air hole. As the fire "groweth hotter the ordinary spirit of wine expands itt selfe pressing upon the mercury & the mercury the Pinn I & so closeth the hole E & clampe the fire till It comes to a just heate ...".[36] The liquid, expanded by the fire, pressed up on the pin, which pressed up on the spoon on one end, which pressed down over the hole on the other, thus limiting the flow of air. Since the fire required the occult properties of the quintessence of air to burn, as the air supply lessened, so too did the fire, inducing a continuing cycle of expansion and diminution of fire, spirit of wine, mercury, and air, according to a fusion of chemical and mechanical properties. The level of heat at which one wished to keep the furnace burning could be changed by adjusting the level of the pin.

Drebbel did not think of his living instruments as purely mathematical or mechanical device, but as a physico-chemical motion grafted onto diverse mechanical objects. What was important for Drebbel was his understanding of the motion as the prime mover in all natural phenomena, not the arrangement of dead matter to which he might apply the natural motion. Now that he had discovered the prime mover of nature, he could deploy it for artificial purposes as well, attaching it to mills, weights, or springs as befitted a natural philosopher who always stressed use and practice as the origin and ends of his philosophy.[37]

He could also graft the motion onto metric functions. His self-regulating furnace, for instance, could be set at different levels of heat based on the different levels the expanding spirit of wine reached, the same motion we now use to measure temperature. However, the epistemic authority of the cosmoscope did not lie in its mathematical applications, but in the theory which Drebbel used to construct the device.

Few individuals were more interested in the practical concerns of regulating heat in the period than alchemists. Drebbel's furnaces, later imitated by Glauber, gained a long-lived renown among alchemists as effective labour-saving devices: the Leipzig professor Johann Bohn discussed Drebbel's furnace, for instance, in his 1685 dissertation, "On Fire".[38] Yet it was the theory behind the practice that made Drebbel famous and granted him philosophical authority. The academic alchemist Heinrich Nollius offered an explanation for the way alchemists maintained four different "grades" of heat. Since the elements depended upon each other, as Sendivogius and Drebbel had written (said Nollius), alchemists could deploy the fire's dependence upon air to manage fires of different grades through different amounts of airflow.[39]

In fact, the central appeal of Drebbel's cosmoscope lay in its avoidance of mathematical quantities and calculations, as Drebbel's friend and editor G. P. Schagen wrote in his printed edition of Drebbel's dedicatory letter to King James I on the device. "If this knowledge was common among astronomers," said Schagen, "one would not require so many theorems in calculating the planets and other stars, but astronomy would be easy and Copernicus would prosper, since he demonstrated (with reasoning) that the Earth goes around every 24 hours, but this Alkmaarian philosopher can demonstrate the same not only with reasoning but also with living instruments".[40]

DEMONSTRATIVE "MACHINS" IN PHILOSOPHY

The idea that a physical perpetual motion could serve as a cosmoscope revealing all the laws of nature can be traced back to the legend of the Archimedean sphere. According to Claudian's epigram on the sphere and other classical sources, Archimedes built a tiny world in glass, revealing instantly all the motions and laws of nature to the gaze.[41] Almost all cosmoscopes drew upon this ancient fantasy of instant, easy knowledge based in working machines. Even Drebbel, who advertised his ignorance of Latin and otherwise always scorned citations, claimed to restitute the lost Archimedean sphere which Cicero had described ("Cicero schrijft / dat Archimedes had een Spheer gemaekct/ die hem eeuwelijck na den loop des Hemels conde beweghen").[42]

The most celebrated version of Drebbel's perpetual motion, the one he presented to King James I and subsequently installed in Eltham Palace outside London, was not a sphere of glass. It had a central sphere of gilt brass surrounded by a circular glass tube, half filled with water. The water moved back and forth twice a day, purportedly showing the motion of the ocean. Above the sphere was a dial which showed the phases of the moon, and on the face of the sphere were the dials of an astronomic clock. One of the spectacular features of this clock was its ability to self-correct (just as the furnace self-regulated), displaying a 'magnetic' sympathy with the sun. Johann Moriaen informed Justin van Assche, Isaac Beeckman and Olaus Borrichius of this aspect of the machine.

> He related that he saw the perpetual motion of Drebbel operate (perhaps out of Mercury) in glass with a clock, so magnetically that if the sun is covered by clouds for two hours, at the moment the sun appears the hand of the clock would shift, for example from the 12th to the 2nd hour.[43]

Also associated with the machine at Eltham was a keyboard that played by itself when the sun shone. Thus, Drebbel's most famous installation of his motion was grafted onto mechanical objects (such as clocks or stringed instruments). It was not simply a glass orb displaying the motions of the heavens, as in the classic Archimedean sphere, nor a purely alchemical "element-glass" showing the *rota elementorum* within a retort. However within his texts, Drebbel did state that he could build a chemical microcosm in glass, and, as noted above, he compared his sphere himself to the Archimedean sphere. Philosophical discussions of Drebbel's perpetual motion often referred more to the traditions of the Archimedean sphere and the "element-glass" than to the actual structure of the machine which Drebbel installed at Eltham Palace.[44]

Although the idea of the cosmoscope had long been available, the object did not enjoy philosophical prominence before Drebbel and his generation. The search for a new stoicheology, or theory of the elements, including new theories of heat and cold, brought this object to the fore. The chemical investigation of the hidden vital principle of nature, often related to Fernel's 'second fire', problematized the idea of a manifest temperament based on four Aristotelian elements alone. The theory of a 'second fire' motivated innovative inquiries into latent forms of heat, cold, and light (phosphorus, or the icy fire), which continued over the course of the century and afterwards. Chemical philosophers were interested not only in hidden supplies of powers and qualities, but in how such supplies stirred universal motion.[45] For a generation of academic alchemists eager to incorporate artisanal knowledge into philosophy, physico-chemical "living instruments" offered a new and wonderful means to explore the second fire as the moving force in the macrocosm.

The use of the cosmoscope and related devices as a philosophical centrepiece was a strategy common to many writers of the period. Many of these, arguably, drew upon Drebbel's cosmoscope, although they cited him only obliquely or not at all. Rosalie Colie, Graham Rees and Arianna Borrelli have pointed out the similarities between Francis Bacon and Drebbel, especially in Bacon's increasing use of *vitra calendaria*.[46] Yet, Bacon himself referred only obliquely to Drebbel as "Dutchmen" and to his cosmoscope as the "imposture of the imitation of the tides".[47] Robert Fludd is another well-known example of someone who only indirectly referred to "counterfeit Masters or Patrons, in this our age". Fludd's claim that the weather-glass was not a modern invention is often the reason given for rejecting Drebbel as its inventor. Yet less interesting than questions of priority in invention, is the way Fludd, like Drebbel, armed himself with a single, personal philosophical centrepiece, or what he called a "demonstrative machin" or "experimentall Instrument, or spirituall weapon" in his *Mosaical philosophy*, where it served as an archetype of the universe. He also deployed it "to demonstrate the verity of my Philosophicall Argument" in the *Utriusque cosmi historia*.[48]

The cosmoscope intervened between philosophical theory and knowledge demonstrated through practice. It not only served to offer experimental or "demonstrative" proof for a philosophical text, but added philosophical authority to collections of secrets. As William Eamon has argued, John Bate signalled his pretention to philosophical authority by prefacing his collection of secrets with a single philosophical centrepiece showing the generation of winds. "The knowledge of this, with the rarifaction of inclosed ayre, is the ground and foundation of divers excellent experiments not unworthy the knowledge of any ingenious Artist whatsoever", claimed Bate.[49] This single demonstration formed the ground for a variety of secrets (including a number of thermoscopes), just as it served as a microcosm showcasing a plethora of natural motions.

Athanasius Kircher, S.J., offers an easily proven example of someone who drew upon Drebbel's use of the cosmoscope as a philosophical centrepiece without citing him. In his great work on the magnet, Kircher denied that Drebbel's perpetual motion machine was a true perpetual motion.[50] Yet elsewhere, in his section devoted to the theory of the elements, Kircher lifted passages often verbatim from the 1621 Latin translation of Drebbel's *On the nature of the elements* (see Appendix). Kircher entitled this section the magnetic theory of the elements; it was magnetic since the elements attracted each other with great force and required each other to live. Fire, for instance, sucked air towards it, becoming hotter with more air, but dying when deprived of it. Kircher followed this theoretical section with a series of experiments proving his theory. In Drebbel's original, this would have been the retort demonstration, showing the mutual transformation, attraction, and movement of air, water, and fire. Kircher replaced the retort demonstration with a thermoscope.

In the motion of the water upwards through heat and downwards through cold hides a wonderful secret of nature, namely the entire motion of the universe, he said. Kircher, like Fludd, designed the thermoscope as an archetype of the world, with its various sections consigned to various temperaments, winds, and air qualities of the world.[51] He described how the thermoscope displayed an analogy with the magnet since the southern heat of the sun pushed the liquid away from the southern tip of the thermoscope, just as the southern tips of magnets repelled each other. Yet, asked Kircher, was this elementary force truly magnetic, as so many stubbornly claimed?[52] Even a friend of Kircher's, a not unknown philosopher ("haud ignobilis Philosophus"), had written to him concerning this "magnetic" movement.

Kircher did not name his friend, but this person was most likely Nicholas Cabeus, S.J., who in his *Magnetic philosophy* of 1629 had described the magnetic movement of the thermoscope. Cabeus related the opinion of another person, who absolutely declared this motion to be that of an animate object; this person had been an eye-witness of the liquid "a certain Englishman" had sublimated and placed in a glass, where it perpetually fluctuated, during the time of Rudolf II.[53] Despite the brevity of Drebbel's stay in Prague, eye-witnesses there did have the chance to observe his glass showing the motion of the tides.[54] Cabeus denied that the motion was animate, since when he talked to other eyewitnesses, he discovered that it was due to the alteration of the "inconstant air", according to the same phenomenon by which everyone "here in Italy in the past few years has been able to measure the degree of cold".

Yet the fact that this instrument had become common should not make it any the less significant, said Cabeus. Indeed, he went on to argue that the motion witnessed in the thermometer, while not quite at the level of life, was not as simple as unidirectional gravity or levity. Mathematicians and Aristotle agreed, said Cabeus, on three possible directions of movement. The movement of the elements was only monodirectional, but living objects could move in all three directions. Cabeus, went on, however, to define a new, median type of bidirectional magnetic movement witnessed in the thermometer which intervened between the simple elements and living things.[55]

We have slowly peeled back several layers of interpretation. Some eye-witnesses understood the cosmoscope as a "living instrument". Cabeus re-interpreted its movement as a median, magnetic motion intervening between life and the simple movements of the elements. Kircher, while lifting pages from Drebbel's *On the nature of the elements* and calling it a "magnetic" theory of the elements, denied that the movement was truly magnetic, much less animate. Yet even the compromising

Cabeus already performed an act of re-interpretation by participating in a redefinition of magnetism.[56] Magnetism meant something entirely different to him than it did to some alchemical magnetic stoicheologists, for whom *magnesia* did not intervene between the elements and life, but connected them.

What alchemists such as Khunrath, Sendivogius and Newton called *magnesia* was not an actual lodestone nor a bidirectional movement, but a material substance which attracted the spirit of the world, that is, the vital agent diffused through all things.[57] For some alchemists, witnessing a 'magnetic' relationship between the motion of the cosmoscope and the motion of the elements in the macrocosm (such as the "inconstant air") did not deny but confirmed that the instrument was living. The validation of a 'magnetic' theory of the elements through the successful working of a single, pansophic cosmoscope was a welcome event much celebrated by the academic alchemists seeking to combine alchemical literature and practice with the theories of academic medicine and physics.

LIVING INSTRUMENTS ENTER THE ACADEMY

As alchemy entered the university at the turn of the seventeenth century, an ancient tradition of alchemical operative knowledge merged with academic natural philosophy in Central Europe. Placing a premium on knowledge found through practice, academic alchemists sought out the works of practising artisans to introduce into their curricula. As a result, Cornelis Drebbel was one of many vernacular artisanal philosophers granted authority in philosophy within the academic curriculum. Academic alchemists also had to defend the new place of alchemy within the encyclopaedia of knowledge by developing a sophisticated metaphysics. A major moment in the introduction of alchemy to the academic study of medicine was thus the publication in 1611 of Johann Hartmann's "chymico-medical" dissertations at the University of Marburg, which married artisanal practice to a new metaphysics.[58]

The collection included two dissertations, the *Hermetic disputation* and the *Apparent contradictions*, defended by Hartmann's son-in-law Heinrich Petraeus (1589–1620), whom Prince Moritz would appoint to the Marburg medical faculty in 1610 to introduce a vitalist natural philosophy there.[59] In the highly unconventional *Hermetic disputation*, Hartmann offered a Dantaesque allegorical pilgrimage through the layers of nature. This journey followed the "straight highway to the centre of truth", allowing the disputant to avoid the "labyrinths of opinion".[60] Hartmann thus abjured the normal structure of the disputation; here were no theses proposed, but visions observed.

With Hermes as his guide, the narrator passed through the various spaces of the temple of nature, and at each stage noted another level of an extensive, pluralistic system which was highly Fernelian. Hermes informed our narrator that the green lion he saw shining there was the "incombustible sulfur, the fire of wisdom, the living fire of nature" itself, which Hippocrates described as moving all things.[61] The stone with the circle of the sun upon it signified the "internal sun, the native heat, much more noble than the elements, which corresponds to the stars, and through whose perennial circulation our blood is nourished with vivifying spirit — the primigenial moisture".[62] Linda Allen Deer has clarified the relationship between these entities in Fernel's thought. "All things which burn, Fernel explains do so simply because they contain a certain oily material which is able to support flame ... the 'primigenial moisture' ... corresponds to the 'oil' which is the fuel of the ordinary flame. Heat: flame: oil: : celestial heat: spiritus: primigenial moisture".[63]

Hartmann did not cite Fernel as his source in that dissertation, but he did so in *Reconciliation of apparent contradictions in dogmatic & Hermetic medicine*, a more traditionally structured disputation. There Hartmann developed a stoicheology which would integrate manual investigations into the classic subjects of physics through the deployment of Fernelian theory. Hartmann argued that the mere interaction of elementary qualities could not explain the specificity of natural bodies in generation and development. Rather, "a higher and nobler cause is sought, which like a craftsman governs their action and directs them to a certain result".[64] Like Fernel, Hartmann quoted Aristotle to show that even the Stagirite accepted two different types of heat, a celestial and elementary one.[65]

Thus, living things had two types of temperament; one which derived from the concordance of the four elements and was mutable, the other which was the form and remained constant. Had Fernel arrived at this distinction, he could have built his account of disease upon a more solid foundation.[66] Since the end of mixture is a perpetual succession and renovation aimed at the preservation of the individuals of a species, we can also explain the "aforementioned movement of the perpetual motion" which corresponds to the motion of the heavens. This form of the elements is responsible for the constant vicissitudes of terrestrial things.[67]

Hartmann referred to an account of Drebbel's perpetual motion appended to the dissertation among the *Epithemata*.[68] There Hartmann described the

> perpetual motion of the Dutchman Cornelis Drebbel, which is seen in England, representing the eternal motion of the stars, the passage of time, and the tides of the ocean precisely, and also his musical organ which emits a most pleasant harmony in the sun, without being touched by any finger, but is silent when it is cloudy. It is agreed that it is moved, turned, and sustained by the *anima mundi* or spirit of the universe, astral and insensible, attracted, infused, and enclosed within that sphere and instrument through a Chymical artifice of magnetic power.[69]

The source for this account was Johann Hartmann's associate Johann Ernst Burggrav. A promoter of sympathetic cures, a magnetic blood-lamp, and electrical weapons, Burggrav described himself as a friend of Drebbel's and a long-term *domesticus* of Johann Hartmann.[70] Burggrav travelled to England in 1608, where he met Drebbel and observed his cosmoscope installed at Eltham Palace in London.[71] Indeed, Burggrav wrote to his Dutch friend Marcellus Vranckheim sometime before 1609, describing the device. Vranckheim, in the midst of an academic peregrination, responded from Padua with a thirty-nine page tribute to Drebbel's invention and other wonderful discoveries of contemporary Netherlanders.[72] The letter, re-printed several times, served as a key text for defenders of sympathetic magic.[73] Vranckheim himself eventually converted to Catholicism and renounced his magical views, as the Jesuit Johannes Roberti, the attacker of the sympathetic magic practised at Marburg, gleefully reported.[74]

On the basis of Burggrav's report, Vranckheim wrote that the machine was motivated by the "little, as they say, magnetic spark of the *Anima Mundi*, or the insensible astral spirit of all things, the harmony of superior and inferior things, that is, the agreement of the macro and microcosms" infused within the sphere, and showing the ebb and flow of tides precisely.[75] This spirit was from the spirit of the world or the "generic spiritual form", that is, it was the fifth element of the world, uniting corporal and intellectual realms.[76] Vranckheim also described Drebbel's other invention installed at Eltham, a self-playing clavier, as having the same motor, "by means of which it can, when sunny, emit a heavenly symphony without being touched by a single finger".[77]

The inclusion of Burggrav's account of Drebbel's cosmoscope in a key dissertation conciliating between Galenic and Hermetic medicine and introducing vital philosophy to the University of Marburg showcased the pansophic ambitions of Hartmann's philosophy. As the author of the *Introduction to vital philosophy*, a work that has been ascribed variously to Hartmann and to Burggrav, put it, all of philosophy, astronomy, physics, and alchemy was but the study of the essence and faculties of this one interior and essential Form of all things existing in either heaven or earth.[78] If Descartes intepreted physics as mechanics, Burggrav and Hartmann interpreted philosophy, astronomy, physics, and alchemy as the study of the motor of Drebbel's cosmoscope.

SEEING NATURE NUDE: LIBAVIUS'S RIVAL INTERPRETATION

Contemporaries recognized the link between the Burggrav/Vranckheim account and the Petraeus/Hartmann dissertations. Daniel Sennert referred to Vranckheim's description of Drebbel's sphere, citing it in his own work which purported to conciliate Galenic and chemical medicine, his *De consensu* of 1619.[79] He then immediately proceeded to attack "many Ramists and modern Chymists", and although he did not name them, he did cite verbatim from Hartmann's *Hermetic disputation* as an example of their views.[80]

The rector of the Coburg Gymnasium and famous academic alchemist, Andreas Libavius, also opposed both Petraeus/Hartmann dissertations, including Hartmann's interpretation of Drebbel's perpetual motion machine. Libavius had already formulated his own interpretation of Drebbel's natural philosophy as based on the idea of a latent heat or second fire found within the earth. However, unlike Hartmann, Libavius did not attribute vitality, animation, and generation to this second fire. Nor did he think that this fire could be freshly drawn down from the heavens in order to impress a soul into matter. Rather, sources of movement, such as the second fire, already lay hidden in matter, and could be uncovered there through alchemy.

Libavius clarified his chemical notion of the 'second heat' while defending alchemy against those French academic physicians who sought to protect Fernel's legacy from the alchemists who appropriated their master's theories. Jean Riolan the elder, for instance, claimed that transmutation could never be achieved through art. The celestial essence could never be found, he said, in the elementary sublunar realm. Libavius countered that through spagyria, chymists could separate such important entities such as that heat which is not elementary, but celestial in origin, as Aristotle (no doubt following Hippocrates) wrote.[81] Certain chemical substances, like the tartar of wine, could be made to elicit forms of latent heat. This heat came from more than the sum of its parts. It was not contributed by any single element, but lay hidden in cold, mixed bodies: "Chymists certainly separate a certain fiery substance out of mixed bodies, such as a very strong fire from the tartar of wine, so that it brings forth a fiery effect, which neither the earth, nor the phlegm, nor the vapid part, nor even the spirit of wine has".[82]

Besides heat, other qualities associated with the elements could also thus be discovered hidden within bodies. They might even all be hidden together within a single body. For example, said Libavius, "Even the common philosophers [*plebei Physicii*] can guess that the faculties of different elements are in" saltpetre. Among the many wonderful effects of saltpetre Libavius described were hidden cold (saltpetre dissolved in water instantly chilled it) and hidden heat (saltpetre pressed in the hand heated up and then burst apart). The many spirits similar to air and fire it concentrated within it were released in the explosions of gunpowder.[83]

Gunpowder offered alchemists a common and spectacular example of how hidden qualities could be contained in substances and released at will through artifice. Drebbel, for instance, described breaking saltpetre and making it change into the nature of air in *On the nature of the elements*.[84] Such chemical effects proved that the nature of the elements lay hidden, and needed to be explored through art. Although military engineering often serves in historiography today as evidence of a concomitant rise of the mechanical arts and mathematical sciences, guns were yet another device that included both chemical and mechanical parts. The Ordnance Office under Charles I was run by two practising alchemists, Drebbel and his patron, Lieutenant General John Heydon. Heydon, a reader of Hollandus and Nuysement, inherited Drebbel's self-regulating ovens and experimented with them alongside his friend Kenelm Digby.[85]

While Libavius defended alchemy from Riolan through reference to the celestial fire hidden in the elements, spagyria faced another opponent in Pierre le Paulmier, who based his attacks upon the celestial fire itself. Natural things contained the celestial fire, placed there by God. When alchemists separated these natural substances through the use of elementary fire in the furnaces, they destroying their original power and replaced it with something artificial.[86] Thus the alchemists could never find the quintessence through their furnaces.

In defence of alchemy in his *Fire of nature*, Libavius reviewed the various ways that chymists could obtain various quintessences within their furnaces. When alchemists referred to the elements, he said, they usually were not referring to four simple essences. They might, for instance, refer to elements as containers for other powers. Or, in its most mystical sense, the element referred to a state analogous to one of the four elements, through which matter passed on its way to becoming the philosopher's stone. This rotation of the 'elements' could be achieved by activating the inner fire hidden within earth through the application of an external fire, precipitating cycles of elemental transmutation, until the inner heat latent within earth began to work.

> For earth in this magistery is not cold, but hot: so too is the earth of the world not that which the babbling philosophers make up in their commentaries on the elements, but that which sense shows is full of fire on the inside, that which Aristotle was forced to confess, and which Hippocrates acknowledged along with those who judge that the power of fire is greater in earth than under the moon, seeing that in earth it is in act & potency.... From earth it is called back to water, and then it goes off into an airy body.... From air it passes into a fixed fire, if it pleases the artisan, and that through no other artifice than the continuation of external fire....[87]

The means of doing this by an artisan at his furnace had been fully revealed by writers such as Michael Sendivogius and Cornelis Drebbel.[88]

Libavius elaborated his views of Sendivogius and Drebbel at length in a folio collection of the best artisanal writers (whom Libavius termed "Monads") translated and interpreted for young students, the *Hermetic revelations.* Thus, very soon after the 1608 German translation of *On the nature of the elements*, Drebbel's little book entered the new canon of academic alchemy in a Libavian guise. Libavius read *On the nature of the elements* in light of an extensive alchemical literature, from Hermes Trismegistus to Sendivogius (who, Libavius claimed, said in Latin the same things Drebbel said in German).

For instance, he compared Drebbel's first chapter to the Hermetic *Emerald tablet*, a classic source for the importance of discovering fire within earth, and its claim to offer "*the entire thelesmos of the entire world*", or as Libavius defined it, "a simulacrum of the perfect works of the natural world in the elementary regions, and even of creation". Yet Libavius did not claim that this simulacrum offered automatic knowledge of the natural world. Rather, knowledge of the elements emerged via induction during the process of producing the philosopher's stone. He interpreted the Hermetic sentence, "*You see philosophy just as in a small mirror*" as "You have theoretical and practical inductions, not so much through the completed stone, as through its preparation, when you see nature in the nude, as Sedinvogius [*sic*] writes".[89]

Yet even inductive knowledge of the macrocosm through observations of the alchemical retort, or seeing "nature nude", troubled Libavius. There were parts of nature which could never be seen. Despite Libavius's attention to and respect for Drebbel, he took offence at the idea that macrocosmic nature was exactly captured within the microcosm of the retort. Commenting upon Drebbel's retort demonstration in Chapter Four, Libavius denied that it was possible to encounter nature nude with one's hands.[90]

Libavius appeared to grow more critical of Drebbel when viewed through the lens of Sendivogius, his seventh and final Monad. Sendivogius's appeal to *magnesia* led Libavius to satirize both his and Drebbel's overall empirical epistemology. Who would deny that the earth has a magnetic power, called *magnesia*, to attract the life-giving portions of the air? "Drebbel saw it in his little philosophical furnace; Sedinvogius [*sic*] saw nature nude.... This is that imaginary philosophy."[91] The generation theory of magnetic stoicheology particularly attracted Libavius's ire, since it showed how vitalist philosophers derogated God's creation of life. Rather than referring to specific *semina* created by God, Sendivogius (and Drebbel too according to Libavius) explained generation entirely through the cyclical motion of the elements they observed in the alembic. They saw how the misty mercury rose from the matter at the bottom of the alembic (called empty or de-souled) yet appeared to lust to be rejoined to matter like an iron to a magnet. After having been ennobled through a long circulation and agitated by elementary qualities, the mist united with matter and was called a sperm. Convinced that in this motion they had "seen nature nude" and discovered the origins of life, Sendivogius and Drebbel thus based their theory of generation upon a "false foundation".[92]

Although Libavius accepted the existence of the spirit of the world, he did not agree with Hartmann and the magnetic stoicheologists that this occult force, as a sympathetic link between the sensible and intelligible worlds, validated a universal natural philosophy through its formal qualities.[93] Alchemists could not pull down fresh knowledge from the heavens in order to see nature nude. Disdaining shortcuts, Libavius advised his students instead to pull away the cloak of simplicity ("populari tegumine detracto in lucem protrahere studebimus"), concealing Drebbel's secretly sophisticated and difficult text.[94] Like saltpetre, it hid much below the surface.

Soon after writing the *Hermetic revelations*, Libavius encountered Petraeus's 1611 disputation. He responded with a disputation of his own at Coburg in 1612, defended by his student Peter Ziegler, solely devoted to Drebbel's perpetual motion and solar-powered clavier. While, he said, he had already fully dealt with Drebbel's text, he felt he had to respond to Hartmann's interpretation concerning Drebbel's instruments. Libavius proposed and rejected various spiritual motive forces for the machine, from a rational soul, to the genius of a star, to the *spiritus mundi*. He also suggested winds, which could also be considered spirits, and offered examples of winds producing music and motion. However, since the clavier could be silenced by a cloud, which should not affect the wind, he rejected that opinion.

Libavius then returned to Hartmann's opinion voiced in the *Epithemata* of the *Apparent contradictions*. After offering an analytical paraphrase of Hartmann's description of the perpetual motion divided into mode, form, and act, Libavius ridiculed it. He wondered why Hartmann didn't go further and claim that Paracelsus's spirit of the fire (Vulcan) "moves the keys by tugging and releasing heavenly ropes let down to the earth, slowly, or quickly, as the music of Euclid and Boethius require".[95] Instead, he concluded that heat must provide the motion, based on the fact that clouds silenced the music. Such heat was not solar heat nor elementary fire, but the "invisible sulphur and fire of nature". This was not, however, Hartmann's vital, formal heat attracted magnetically into the machine from the sun. It was rather a chemical latent heat, which could be produced artificially through the circulation of the "elements" in the production of the philosopher's stone. The water which moved back and forth with the tide within the machine could be easily explained this way. It was probably some vitriolated, salty, mercurial liquid containing latent heat.[96]

Libavius had a harder time explaining how such a chemical latent heat could produce the music of the self-playing clavier. The clavier played only when the sun shone, yet it was hard to conceive of such a complicated instrument being purely solar-powered. He did not find it probable that unassisted solar heat activated the device, since the musical instrument was a stringed instrument whose keys had to be hit with a great deal of force in order to play. Libavius instead supposed that Drebbel, through his alchemical knowledge of mobile spirits and the ways of circulation, devised a spirit which could be excited by only a very little heat. This would explain how the instrument could be sensitive to such minute changes, such that it stopped playing when a cloud passed in front of the sun.

Another possibility was that Drebbel used here too a chemical containing its own internal principle of "ebullition", as in his marine tide. He could have placed it in very sensitive hollow glass wheels (perhaps even ones made from the famous flexible glass, made from crystal and the philosopher's stone) which could be made to move and turn easily by the vapour of Drebbel's bubbling chemicals.[97] This was much more likely than the "foolishly devised opinion concerning the soul and spirit of the world attracted by a magnetic power, as in the weapon salve". It was "shameful to stray to Metaphysics and fictions immune from disputation", when natural causes were available.

Libavius, already so familiar with *On the nature of the elements,* based his interpretation of the machine on his interpretation of the text. In order to understand such machines, it would be best to question eye-witnesses, and who better than the artisan who would perfectly understand the motion he built?[98] Libavius specified that Drebbel's knowledge of the motive force of heat could be shown through his retort demonstration, and the reader attempting to understand how Drebbel might have employed a chemical liquor such as mercury to move mechanical parts could turn to Drebbel's own theory of the elements.[99]

A year after Libavius's dissertation on Drebbel's perpetual motion, Hartmann complained, in the preface to his 1614 re-edition of his 1611 collection of dissertations, that Libavius had humiliated him in public.[100] Libavius defended himself against this criticism in his own preface addressed to Hartmann in his *Vital philosophy ... according to Hartmann.*[101] He refused to apologize for his 1612 onslaught. While Hartmann, his former friend, had been secretly attacking him behind his back in letters to powerful men, he had been completely free of malice in his public criticism of Hartmann.

> I was accustomed then, and still now, to give the Gymnasium entrusted to me practice with questions both enjoyable and useful for knowledge. Meanwhile I

> ran across your judgement concerning the instrument of Drebbel (whose book I had added to my *Syntagma,* translated into Latin and elucidated with commentary) which seemed to me to agree little with his opinion, but to digress towards something magical of the sort which Crollius proposed. I disputed against it without affront to you, and you may also differ with me. If you believe that you understand it more correctly, come, let's debate the same question again, and you can try to undermine my opinion. We'll see what kind of man you are.[102]

After throwing down this gauntlet, Libavius painstakingly excoriated the entire *Hermetic disputation,* mocking line-by-line everything Hartmann claimed to see hidden in the depths of nature, including the living fire of nature. Libavius conceded that there was a moving heat which led to generation and growth, yet this heat was not living.[103] In general, he satirized what he cast as a claim for an absolute, immediate, and easy reformation of knowledge and society which Hartmann shared with the Rosicrucians.

Libavius drew this comparison again in his notes on the Rosicrucian *Fama*, which seemed strangely similar to the *Hermetic disputation*.[104] In particular, the tomb of Christian Rosencreutz in the *Fama*, which contained such widely-held *desiderata* as a perpetually moving microcosm and perpetually burning lamps, recalled Hartmann's description of the temple in his *Hermetic disputation*.[105] While "the chamber of the tomb of Christian à Rosy Cross is utterly astonishing and incredible", Johann Hartmann too "was led by Hermes into a cloister that was both inside and outside the world, where he saw everything divine and human as though depicted in the shield of Achilles or Aeneas".[106] The Rosicrucian's microcosm, he said, was perhaps the Archimedean sphere or perhaps the magisterium in which they saw nature nude.[107] It recalled the epistemic claims Claudian made for the Archimedean sphere. Libavius played upon Claudian's verses praising the Archimedean sphere, in which Jupiter smiled upon seeing a man-made microcosm. Jupiter's smile became a guffaw when Libavius imagined him considering a microcosm within the tomb of Christian Rosencreutz. "Jupiter laughed at the sphere of Archimedes. What would he say or do when seeing that tiny monument, in which is the natural & artificial macrocosm?"

Libavius did not doubt that nothing could be more desirable (*optabilius*) in all of Philosophy than an epistemic physico-chymical cosmoscope. It would be wonderful to have a compendium of past, present, and future things. Such a compendium would especially please Libavius if the knowledge of all things and their change over time would lead to an understanding of causation in the world. "How much would the most beautiful microcosm, a compendium extracted of all things past, present, & future, delight me, especially if it would expose to view the causes of all operations at once?"[108] Yet, not only were such claims impossible, they were also dangerous and disorderly. The Rosicrucian's little world, like the Pythagorean sphere of the enthusiastic Hartmann, circumvented the careful literary empiricism practised by Libavius, and allowed an instant inspection of the Holy of Holies through a living microcosm. It mixed together "everything divine and human", "natural and artificial", and "past, present, and future".

Worst of all, the Rosicrucian promise of a total, comprehensive, and instant encapsulation and transmission of all knowledge did not respect man's fallen nature. Libavius rejected Croll's claim that Adam could see all of Philosophy, regaining his lost Edenic knowledge through the philosopher's stone, just as had "Drebelius, Sedinvogius and others". "Such a thing should not be claimed, but proven", he said.[109] Combatting the idea that the microcosm is in harmony with the macrocosm, Libavius argued that the world is far too complicated for a simple harmony. He conceded that harmony reigned in the world before the fall, or in the heavenly Jerusalem. But in this world, subject to original sin, everything fell prey to dissonance, disorder and decay. "Your tiny world, your little Archimedian, Drebbelian globe" might contain a single melody, said Libavius, but the macrocosm was full of difference.[110]

Libavius and Hartmann themselves shared many similarities. Both were German semi-Ramist academic alchemists.[111] Both introduced the study of Drebbel and his works to the academy in search of a clear, useful, and didactic natural philosophy. Both accepted the idea of a Fernelian second fire and interpreted Drebbel's works in that light. Yet their interpretations differed radically. For Libavius, this fire was a latent heat found in certain chemicals, like the tartar of wine or saltpetre, which could be extracted and made to heat on its own at certain times. Thus Libavius determined that Drebbel used the 'fire of nature', or a heat-containing chemical, to provide the heat driving his machine. For Hartmann, this heat was a vital celestial force carried by the spirit of the world, which kept all things alive and in motion. He, *à la* Burggrav, believed that Drebbel had imprinted the solar powers of this fire into the machine, which explained both how it remained in motion as well as its 'magnetic' relationship to the sun.

Such philosophical differences entailed a dispute over the epistemic potential of alchemical observation and the proper course for academic alchemy. Their academic treatments of Drebbel's machine ignited and exemplified these differences. Hartmann argued strenuously for the certainty of chemically-derived knowledge. By taking the highway to the hidden heart of nature, Hartmann resolved apparent contradictions and scorned disputations. Libavius, by contrast, championed the universal character of the chymical discipline as available to all through the humanistic study of texts and not individual divine inspiration or a connection to superior realms. In this he typified Ramus's literary empiricism, yet his rejection of the macrocosmic-macrocosmic relationship in chemistry rendered him unable to support alchemy as a "high science" leading to knowledge of the macrocosm. Bruce Moran has emphasized the "polemical fire" Libavius deployed instead to carefully delineate the proper path for alchemy.[112]

PLAYING WITH MACHINES IN SCHOOL

Despite attacks by the likes of Sennert and Libavius, Hartmann's shortcut won followers in the schools, especially among Central European Ramists. Howard Hotson argued in *Commonplace learning* that the greatest concentration of Ramists could be found not in England, but in Central Europe. Harried teachers in semi-Ramist *gymnasia*, *gymnasia illustria*, and universities of small Central European principalities required an easily comprehensible physics. They especially sought learning which could benefit the patrons of their often newly-founded institutions. It was in such schools that alchemy, with all of its utilitarian possibilities, entered the academy.[113] It was also there that the dream of seeing nature nude through merely playing with a cosmoscope beguiled teachers.

Johann Heinrich Alsted, an influential pedagogue at the relatively new Herborn academy, urged his students to learn about nature through a physico-chemical cosmoscope. He was a great admirer of Drebbel's philosophy. Ultimately, Alsted would reprint the entire 1621 Latin edition of Drebbel's works edited by Joachim Morsius in a 1626 philosophical textbook, and two of Drebbel's tracts within his famous *Encyclopaedia* of 1630, calling Drebbel the best writer on meteors ever and one of the two best on the elements. One of Alsted's students, Johan Sibert Küffler, even married Drebbel's daughter.[114]

Alsted first encountered Drebbel, however, not through Morsius's edition of the texts, but through Burggrav's description of the machine. In his *Cursus philosophici encyclopædia* of 1620, Alsted cited Burggrav's description of the perpetual motion as evidence for the *spiritus mundi* linking superior and inferior realms and enabling the construction of an *apotelesm*, or perpetually moving microcosm.[115] Like Hartmann, Alsted championed Drebbel's natural philosophy as based in the magical (and encyclopaedic) art of micro- and macrocosmic harmony, as proven in the use of the *spiritus mundi* within his perpetual motion machine. It was this link between microcosm and the universal structure of the macrocosm that granted the machine its philosophical status, by animating the mechanical parts of the machine with a physical form. As Alsted wrote in the *Philosophical compendium* of 1626,

> Nobody is ignorant of how much the exploration and discovery of the perpetual motion has exhausted the acumen & diligence of the greatest minds, unless he is perchance ignorant of natural philosophy. The autodidact Cornelius Drebbel also wished to attempt his own trial of this matter. I give you here his ideas in a brief letter. I also warn you not to separate in your thinking the mechanical perpetual motion from the physical perpetual motion. For the latter gives the former its entelechy.[116]

Many learned from Alsted to seek the fire of nature within Drebbel's earth.[117]

The Hartmann interpretation was also taught at Steinfurt, another new gymnasium modelled after Herborn.[118] The Kassel alchemist Heinrich Nollius, a student of Petraeus, introduced the study of alchemy to the Steinfurt Gymnasium. To that end, he wrote a number of alchemical textbooks offering clear alchemical pedagogy, including his 900- page compendium, the *Sanctuary of nature* of 1619. Alsted praised Nollius's works as model introductory texts for students, and cited Nollius on the role of earth as a receptacle for the spirit of the world.[119]

Nollius, like Alsted, cited Drebbel as an authority at many points, quoting frequently and at length from *On the nature of the elements*.[120] Like Libavius, he read Drebbel in light of the Hermetic Emerald Tablet, Basil Valentine, and Michael Sendivogius. Through the successive conversion of the "elements", the "rota elementorum", the earth could be brought into a ferment, and the motion of the heat would impel its purer parts towards the surface. Nollius however, as a vitalist, claimed that during these chemical processes the soul of the world linked to the sun would be "impressed" into matter ("animamque universi e Sole in ipsam affatim singulari artificio impresseris"). Thus Drebbel's perpetual motion was alive and a true microcosm, showing the actual motions of the heavens.[121]

Nollius recommended that the student of astronomy consult such a living globe in the *Hermetic physics* (one of several works included in *Sanctuary of nature*). There he described two different types of spheres. One was merely imitative; through it, the student could quickly learn the traditional doctrine of the sphere. However, the student could never gain new knowledge of the cosmos from a merely imitative representation. The second type of globe was a living microcosm, in which all the heavenly bodies were moved by the universal spirit just as in heaven. Both the Rosicrucian globe and Drebbel's sphere were of this type. "In England", said Nollius, "a perpetuum mobile is to be seen, which similarly represents the entire world, and shows in a wonderful way the motions of the stars, the conjunctions and oppositions of the planets and even the disposition of inferior things, with precision. The author of this perpetual motion is Cornelius Drebel, a Philosopher not to be despised".[122] Nollius advised his students to seek out philosophers who had built their microcosms with their own hands ("manu sua"), like Drebbel, who boasted that his knowledge came from his hands ("Dieses lieber Bruder habe ich von der natur geschriben wie ich solches mit der handt befunden").[123]

Daniel Mögling, a scion of eminent Tübingen academics and future court physician to Landgrave Philipp III of Hessen-Butzbach, repeated Nollius's advice.[124] In his *Perpetuum mobile* of 1625, Mögling cited Hartmann, Vranckheim, and others on Drebbel's cosmoscope. He also directed the reader who wished to understand Drebbel's device to consider the retort described in Chapter Four of Drebbel's short *On the nature of the elements* ("Wer mehrere Nachrichtung begehret, lese das kurtz ...Von Natur der Elementen ... vornemblich aber das vierdt Capittel desselven von der Retorten").[125]

Like Drebbel, Mögling built his own machine through his knowledge of natural magic rather than mechanics, and therefore claimed it was not open to accusations of impossibility. Although it could be applied to mechanical purposes, Mögling preferred that it serve nobler ends. Instead he suggested that it serve as a sort of Rosicrucian microcosm, showing the motion of everything from the planets to the tides. Thus, merely by playing with it, schoolchildren could gain an immediate knowledge of nature without difficult mathematical calculations.[126] Indeed, in one of his Rosicrucian pamphlets, the *Prodromus rhodo-stauroticus*, Mögling suggested, in a direct translation of Nollius's advice, that he who wished to understand the harmony of the macrocosm should seek out those philosophers who have themselves built perpetual motions, since such devices showed as in a compendium the motion of heaven, the elements, and the natures and properties of all things.[127]

CONCLUSION

In the early seventeenth century, the authority of the cosmoscope and of the artisanal philosopher who constructed it grew from the union between matter and form, practice and theory, and mechanics, physics, and chemistry. Such a blend proved potent within the new hybrid discipline of academic alchemy. A distinctive Ramist preference for pedagogical ease, comprehensiveness, certainty, and practice coupled with vital philosophy encouraged pedagogues to introduce "living instruments" into their curricula. Within these animated microcosms, they hoped to show their students all the laws of the macrocosm, as though within the Rosicrucian microcosm.

The popularity of the cosmoscope as a single construction proving a pansophic philosophy grew out of the academic alchemists' quest to reform knowledge through artisanal practice. This suggested great respect for the maker of these epistemic machines and necessitated a close attention to the artisan's own philosophy and interpretation of the device. Academic alchemists and others in the orbit of Johann Hartmann pointed out the relationship between Drebbel's retort demonstration in *On the nature of the elements* and his perpetual motion. They recognized that the central hollow globe of the perpetual motion contained air which, by rarefying or condensing, pushed the water in the attached glass tube back and forth. However, this recognition of the relationship between the perpetual motion and Drebbel's theory of the elements did not necessitate a mechanical interpretation of the machine. Rather, this group of interpreters shared a particular metaphysical foundation for their understanding of elementary transmutation.

They argued that Drebbel, employing the spirt of the world, had attracted a vital fire into an artificial object, thus animating it. It was this heat which provided the constant source of motion for the chain of elements contained in the machine. Since this heat was drawn from the celestial fire, it also explained the machine's correspondence to the sun and to the motion of the other heavenly bodies. As a living microcosm, the machine therefore gave direct access to the real movements of the macrocosm, suggesting thrilling philosophical and pedagogical possibilities.

Hartmann's rival Andreas Libavius also interpreted Drebbel's machine in light of this second, non-elementary occult heat. However, he denied the heat's metaphysical vital and formal qualities. The fact that Drebbel employed hidden forms of heat within the chemicals contained in his machine did not grant the machine a soul. It also did not connect the machine to the macrocosm, and thus provided no certain knowledge of the structure and movement of the heavens. Libavius addressed this question in his 1612 dissertation on the perpetual motion. Since philosophers themselves were still disputing the structure of the heavens, there was no way a machine could be built to give certain knowledge of the actual heavens. At best, the machine could represent probable theories, such as Copernicanism, but it could not lead to new knowledge of nature.[128] It could not, as so many hoped, resolve all disputes and usher in a new age of Edenic knowledge. The details of Drebbel's process for the philosopher's stone could be uncovered only through the careful collation of Drebbel's works with an extensive alchemical corpus, rather than the simple observation of nature nude.

Drebbel's natural philosophy and allied cosmoscope were international sensations. I have reviewed just a small fraction of their reception here. Coupled with the highly public competing interpretations of such titans as Hartmann and Libavius, and the plethora of other writers deploying the cosmoscope as a "demonstrative machine" or "ground" for philosophy, the status of physico-chemical machines in philosophy was assured well before the rise of mechanics. The study of epistemic machines before Descartes points to some of his intellectual predecessors, clarifies the characteristics of epistemic machines which endured the transition to quantitative mechanical philosophy, and complicates the relationship between mechanicks and mechanical philosophy.

According to Domenico Meli, machines gained cosmological significance only after the establishment of mechanics as a discipline central to natural philosophy.[129] Yet Descartes's mechanical model of life emerged after the cosmoscope had been deployed as a philosophical centerpiece for a generation. When Descartes interpreted the heart as a pneumatic self-regulating furnace burning with a Fernelian dark fire, his major innovation was not to interpret the body as a machine, but to interpret a physico-chemical-mechanical device as a physico-mathematical one. This suggests the importance of the history of alchemy even to the study of mechanical philosophy.[130]

The question of the invention of the thermometer, like the understanding of Drebbel's thought in general, has suffered from an interpretive bias in favour of mechanics. Jennifer Drake-Brockman, for instance, has argued that it took someone from Galileo's circle to recognize the relationship between the movement of the perpetual motion machine and the famous retort demonstration from Drebbel's *On the nature of the elements*, rather than the misguided alchemists who sought occult causes for the motion.[131] For similar reasons, the credit for the thermometer often falls to Galileo or Santorio, that is, to those who are perceived as interpreting the motive power of the cosmoscope as mechanical. This view does not do justice to the complexity and ambitions of alchemical thought. The scientific study of heat did not begin nor end with the invention of the thermometer and the mechanical interpretation of motion. Alchemists well understood the relationship between Drebbel's cosmoscope and his "retort" demonstration.[132] Yet for both empirical and theoretical reasons, they did not interpret those motions mechanically. It was as a physico-chemico-mechanical device that the cosmoscope held the most epistemic authority in their eyes.

The cosmoscope, once re-interpreted as a quantitave metric device, eventually lost its epistemic authority, as did its artisanal constructor. It was deployed as a specialized tool in other investigations, experiments, or large scale compilations of data, but it did not offer the comprehensive and instantaneous access to the physical universe it once promised. As a result, the validation of one's philosophical system no longer depended on the successful construction of a microcosm with one's own hand. The sale of thermoscopes distanced the manual labour of physico-chemico-mechanical construction from the practice of experimental validation. The epistemic authority once deriving from cosmoscopic constructions now fell to those mechanical philosophers who used mechanics and mechanicks as dead instruments in their own compilations of natural knowledge.

The once robust respect for a machine-based but non-mechanical philosophy withered, yet the fantasy of an instantaneous and comprehensive machine-based knowledge faded away only gradually. The reconstruction of Drebbel's perpetual motion by Christopher Wren (who also attempted to replicate Drebbel's self-regulating furnace), and its realization by Robert Hooke as a single device which could both measure and record "all the changes, that happen in the air, as to its heat and cold, its dryness and moisture, its gravity and levity, as also of the time and quantity of the rain, snow, and hail, that fall" show that the cosmoscope was slow to die.[133] Of course, the massive meteorological projects of late seventeenth-century collective empiricism depended upon the development of perfectly calibrated thermometers and barometers.[134] Yet the perfection of these metric devices owed less to the right understanding of heat and cold than to the transition of machine-based philosophy from a personal pansophism validated by a single comprehensive construction to the large scale commerce of particulars.

The future of physics entailed the integration of many instruments, individuals, and approaches — including mechanics and chemistry. Although the pansophic autodidact did not survive as the model natural philosopher, Drebbel's all-encompassing persona and his ability to creatively fuse distinct disciplines inspired a new generation of philosophers. For Robert Boyle, Drebbel personified someone who ceaselessly made new discoveries by leaving the bounds of discipline and profession. Boyle employed Drebbel's discovery of a new scarlet dye and the submarine to showcase how new inventions originated in the crossing of boundaries. Scarlet "affords me a notable instance, that Trades may be considerably improv'd by those, that do not professe them. For the most famous Cornelius Drebel, who was the Inventor of the true Scarlet dye, was a Mechanician, and a Chymist, not a Dyer". The "excellent Cornelius Drebell" invented the submarine, despite the fact that "this Inventive *Drebell* was no profess'd shipwright, nor so much as bred a Sea-man".[135] He also discussed the "much admir'd digesting furnace, built by that inventive Mechanitian & Chymist Cornelius Drebel, wherein a Quantity a Quicksilver was soe plac'd" that it served to regulate the temperature of the fire. "Nor", continued Boyle, "is this the onely Mechanicall use that Chymists may make of Quicksilver.... And to add something upon this occasion, I can scarce doubt but that Chymistry may be very much advanc'd if the Practisers of it were well skill'd in Mechanicall contrivances".[136]

Boyle connected chymists and mechanicians here on a practical level just as, as William Newman has shown, he related chymical theories to the mechanical philosophy on a more theoretical one. Yet Boyle also chose to place the motion of the mercury on the mechanical side of that relationship. Some of his contemporaries still stressed the physico-chymical nature of the thermoscopic motions they attached to machines. Both J. J. Becher and G. W. Leibniz believed mechanical clocks could be perfected through attachment to Drebbel's physico-chemical motion. They would thus ground time-telling in the universal course of nature and make it possible finally to solve the problem of longitude.[137] According to Leibniz, the ability to painlessly fuse distinct things and thereby make great discoveries was Drebbel's special genius.

> They say that the famous Drebbel had such a good imagination, that finding a piece of stone in the road, he would remember a hole that he had noticed in another spot that this fragment could fill precisely. That is to say that the combination of things which appear far distant often serve to produce singular effects. And that is also the reason why those who limit themselves to a single investigation often fail to make discoveries that a more expansive spirit who can join other forms of knowledge to the one with which he is occupied will discover effortlessly.[138]

Drebbel was no mere mechanick, and his cosmoscope was no primitive thermoscope. Rather, this physico-chemico-mechanical philosopher and inventor showcased the fusion of disciplines in an era of new hybrids. The future of physics lay not in a sudden shift from vitalism to mechanical philosophy, but in syntheses of both. The history of mechanics and the history of chemistry thus both deserve a place in the study of the mechanical philosophy.

APPENDIX

C. Drebbel, *On the nature of the elements*, transl. by Lauremberg (Hamburg, 1621).	A. Kircher, *Magnes* (Rome, 1641), 570–82.
Chapter 1	
Deus enim exactâ temporis plenitudine, quando illi complacuit, cunctarum rerum Naturas Vero produxit. Initiò quidem, id quod erat subtilissimum, secrevit à caetera massa, factumque est Ignis elementum, occupans supremam mundi sedem, replens infinitum istud alioquin vacuum futurum spatium: circumdans Dei magnifica opera. Scilicet quicquid levissimum est, id sursum ascendit. Iam Deus iterum ab ista massa separans id quod levius, quodque subtilius, effecit elementum Aëris, cuius locus proximè sub levissimo igni,	Ens igitur entium Deus Opt. Max exacta temporis plenitudine, quando illi complacuit, cunctarum rerum naturas verbo produxit, ac primo quidem ex primigenia illa confusionis massa, seu infinito rerum chao, id quod subtilissimum erat productio ignis atque levissimum secernens, lucem sive elementum ignis condidit; hinc omnipotentis virtutis iussu.... Iterum Deus à prima illa hyle, idquod levius erat, & subtilius separans, elementum aëris, cuius locus immediate sub igne levissimo, producit....
Consimili ratione & à reliquiis seiunxit partem subtiliorem humidoremque, atque efformavit cum Tellure Aquam. Aqua verò integram terrae faciem obtegebat haud secus ac ignis aërem aër aquam. Caeterùm omnipotens Dei virtus, terras aquis immersam extulit in altum, nosque in eadem collocavit, ut eò perfectiùs contemplaremur splendorem aeviternae suae lucis, ac se amaremus, quippe qui perfectissimi eramus creati.	Porrò consimili ratione, & à reliqua massae parte Deus, id quod subtilius erat, & humidius separans, efformavit cum tellure aquam, & haec quidem cum non secus, ac ignis aërem, aër aquam, inconvenienter terram circumdaret, ea in alveos inclusa, tellurem aquis immersam in altum extulit.
Sic quandripartitò divisit Deus opera sua in Ignem, Aërem, Aquam, Terram.	Ita quadripartite divisit Deus opera sua; videlicet in 4. elementa,
Intuere hoc Elementum, quàm operosè illustret Aërem!	Quis non videt quam mirificè hoc elementum aerem illustret?

huncque ad similem claritatem perducat, omnes ex eo dispellens tenebras. Ita testatum facit quanta antè obscuritate oppressus fuerit aër. Insuper ab omni humore excrementitio fumisque terrenis eundem expurgat.

huncque ad similem claritatem, ad similem subtilitatem omnis crassitiei expertem ac quaeuis penetrantem, omnibus ex eo depulsis tenebris, ab omni excrementitio humore, fumisque terrenis eundem expurgando, perducere nitatur?

Exemplo & argumento est Ignis noster Culinaris, qui ligno aut cespitibus siccis enutritur, magna vi colligit, & quasi sugendo attrahit ad se aërem: eum nitidum, purum: lucentum reddit, sibique assimilat penitus: Quod ipsum tam avidè tamque impensè facit, ut si fortè intercludatur, subtracto & intercepto aëre (id est quoties suffocari eum contingit) mox intermoriatur ac tenues evanescat in auras:

certè huius rei argument est ignis noster culinaris, qui ligno aut cespitibus siccis enutritur, magna vi colligit, & quasi sugendo attrahit ad se aërem, eum nitidum, purum, lucentem reddit, sibique assimilat penitus, quod ipsum tam avidè, tamque impensè facit, ut subracto aut interrupto aere mox suffocatus intermoriatur ac tenues evanescat in auras;

Finis enim cuiusque idem est ac eiusdem principium, uti testatur quotidiana experientia. Quod è Terra pullulat, ad terram revertitur, quod ex Aqua, ad aquam. Quicquid est, id initiò perfectissimum fuit apud Deum, atque olim itidem ad eandem perfectionem revertetur, tum cùm elementa colliquescent, & pristinum induent splendorem coram Deo. Nihil ibi perditum ibitur praeter iniustitiam.

ita finis cuiusque idem est, ac eiusdem principium, quod è Terra pullulat ad terram revertitur, quod ex aqua ad aquam, & omnia tandem ad eum ceu finem ultimum à quo originem hauserunt, redeunt. Quicquid est, id initio perfectissimum fuit apud Deum, atque ad eandem suo tempore perfectionem revertetur, tum, cum elementa colliquescent, & pristinum induent splendorem coram Deo: nihil ibi peribit praeter iniustitiam hominis....

Chapter 2

Nonne vides quàm atri sint carbones extra ignem? quàm clari sint, quàm lucentes in igne, non minùs quàm lucentes in igne, non minùs quàm ignis ipse. Tantum illis splendorem ignis impertit, ut etiam in formam penitus diversam transformentur: Tum revertuntur ad pristinam suam naturam. Etiam cinis ipse non renuit tandem mutari in substantiam vitro non dissimilem, ac postremo invisibilem

Quis non videt, quam atri ac terrei sint carbones extra ignem? quàm clari, lucidi in igne, non minus quam ipse ignis? tantum [582] enim illis splendorem ignis imperitit, ut etiam in formam pentius diversam transmutentur. Tum revertuntur ad pristinam suam naturam; quin imò ipsum cinerem & arenam, opaca & squalida caeteroquin corpora, ignis tandem ope in vitrum mundissimum, subtilissimum, sibi prorsus simile, diaphanum & propè αορατον corpus . . . .

Chapter 3

Namque ut Ignis vita ipsa est: vivit verò in aëre, haud secus in igne vivit aër, aqua in tellure, tellus in aqua. Ignis aërem perpurgat, aër aquam, aqua teram: unumquodque sibi, suoque splendori, asimilat alterum.

Nam ut ignis vita ipsa est, vivit verò in aëre, haud secus in igne vivit aër, aqua in tellure, tellus in aqua; ignis aerem perpurgat; aër aquam, aqua terram, unumquodque sibi suoque splendori adsimilat alterum.

Calor enim ignis, quemadmodum omnia subtilia & pura reddit, ita ex adverso frigus igni contrarium omnia condensat, constringit, aquamque quasi comprimit, resistens calori ignis, & aëris subtilitati.

Calor enim sive ignis, quemadmodum omnia subtilia, & pura reddit, ita ex adverso frigus igni contrarium omnia condensat, constringit, aquamque quasi comprimens resistit calori ignis, aërisque subtilitati.

Caput II

Magnetica Elementorum vis experimentis ostenditur.

Consimiliter aër ignem condensat, si illius

... ita terra in aquam, aqua in aërem, in ignem frigiditas hujus calorem superârit. Ignis in aërem mutatur, aër in aquam, aqua in terram, ut ante fuit demonstratum.

denique aer mutatur rarefactione, condensatione verò è contra ignis in aërem, in aquam aër, aqua denique in terram ita convertitur,

Chapter 9

Ignis nihil est aliud, quam subtilis aer; aer est subtilis aqua, aqua est subtilis terra: Terra crassus ignis, quemadmodum evidenter demonstrant superius adducta exempla.

ut non incongruè ignis subtilis aër, aër subtilis aqua, aqua subtilis terra, terra verò crassus quidam ignis, & contra terra congelata aqua, aqua congelatus aër, aer ignis addensatus, dici potest. Quemadmodum experimenta irrefragabiliter demonstrant.

Enim vero terra, seu vi ignis, seu naturae ingenita efficacia, resoluta, transmutatur in aquam, fitque sal & quaedam terrae virtus, cujus rei perfectum argumentum praebet calcinatio. Sal ipsum igni dissolutum mutatur in aquam, veluti videre est ex destillatione aquarum fortium: Aqua porro vi Ignis soluta sit aer, aer fit ignis. ut jam ante dictum. Hoc pacto crass obscuraque terra convertitur in subtillisssimum, pellucidissimum, splendidissimum ignem, qui non solum penetrat, illustraque omnia, sed & facit, ut ipsa penetrandi, illustrandique potestatem nanciscantur.

Nam terra seu vi ignis, seu naturae ingenita efficacia, resoluta, transmutatur in aquam, fitque sal, & quaedam terrae virtus, cuius rei perfectum argument praebet calcinatio; sal ipsum igni dissolutum mutatur in aquam, quam metamorphosin prodit aquarum fortium distillatio. Aqua verò vi ignis soluta fit aër, aer fit ignis, ut iam saepè dictum est, & paulò post experientia ostendetur, vides igitur qua ratione terra crassa, obscuraque converatur in subtilissimum, pellucidum splendidissimum ignem, qui non penetrat, illustratque solùm, sed & facit, ut ipsa penetrandi, illustrandique facultatem nanciscantur....

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11. Notably in Svetlana Alpers, *The art of describing: Dutch art in the seventeenth century* (Chicago, 1983), 4–5, 12–13, 23. Pamela Smith, who noted the interpretation of *On the nature of the elements* as a series of alchemical receipts on the title-page of the British Library edition of Drebbel's works (British Library 1033.c.34), offers an important exception. See Smith, *op. cit.* (ref. 10), 163, where she describes the "First Tincture" of Drebbel's Preface and the "Second Tincture" of Chapter Ten. Drebbel's "sperma" is a "tincture taken out of the body of the earth, which must be fixed with spirit through the circle of the elements" ("Tincturam ex corpore terrae desumptam, quam cum spiritû figi debere per rotam elementis"). These descriptions correspond extremely well with Libavius's interpretation (discussed below), who considered the tenth chapter the most important part ("medulla") of the text. Andreas Libavius, "Apocalypseos hermeticae pars posterior", *Syntagma arcanorum chymicorum ... tomus secundus* (Frankfurt, 1613), 328–453, p. 375.
12. He does not appear, for instance, in Katherine Park and Lorraine Daston (eds), *The Cambridge history of science: Early modern science* (Cambridge, 2006).
13. Regionaal Archief, Alkmaar, Weeshuis 16, 360–362v. A German 1608 translation is currently the first extant edition. Johann Ernst Burggrav claimed that translation as his own in his preface to his second edition of Drebbel, *Ein kurtzer tractat von der natur der elementen* (Frankfurt, 1628). Burggrav mentioned that Drebbel had printed a few copies earlier in Dutch to be given to a few friends and philosophers. This must have been the Dutch edition mentioned by Isaac Beeckman in 1619 in his *Journal tenu par Isaac Beeckman de 1604 à 1634*, ed. by Cornelis de Waard (The Hague, 1939–53), i, 346. A portrait of Drebbel dated 1604, copied in many later editions of the work, is still extant.
14. The classic biography remains F. M. Jaeger, *Cornelis Drebbel en zijne tijdgenooten* (Groningen, 1922). For Drebbel as Chief Engineer and his death and burial in 1633, see Edward Murray Tomlinson, *A history of the Minories, London* (London, 1922), 136, 400.
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16. Arianna Borrelli, "The weather glass and its observers in the early seventeenth century", *Philosophies of technology: Francis Bacon and his contemporaries,* ed. by Claus Zittel *et al.* (Leiden, 2008), 67–132; on Descartes, p. 125. Ian Maclean, "Introduction", in René Descartes, *A discourse on*

the method, transl. by Ian Maclean (Oxford, 2006), Note 24.

17. *Ibid*., pp. lx–lxi, although Descartes's method of argumentation was no shorter than Drebbel's, as Maclean claimed there. Seventeenth-century comparisons between Drebbel's inventions and Descartes's mechanical models of life are not hard to find. See Kenelm Digby, *A discourse concerning infallibility in religion* (Paris, 1652), 60–61; Johann Cyprian in Wolfgang Franzius, *Historia animalium*, ed. by Johann Cyprian (Frankfurt, [1687] 1712), 476; J. M. Schammelius, *Dissertatio physica de arte naturae aemula* (Leipzig, 1689), thesis XLVI; Johann Christoph Sturm, "Exercitatio octava de artis et naturae sororia cognatione", *Philosophia eclectica* (Frankfurt, 1698), 416–17. Hartlib compared the two as inventors able to recreate, and thus teach, natural processes artificially. Hartlib, *Ephemerides,* 29/3/62A, 1635, *The Hartlib papers CD,* 2nd edn (Sheffield, 2002): "De Cardes hase a new device to make a Statua or Babie to walke vp and downe to eat to concoct to disgorge itself, which is admirable also for didactiks to shew the manner of concoction.... So Drebbels feate to shew the didactik of thundring and lightning."
18. Wilhelm Schmidt, "Zur geschichte des thermoskops", *Zeitschrift für Mathematik und Physik*, viii (1898), 161–74, p.165; H. A. Naber, "Cornelis Jacobsz Drebbel", *Oud Holland*, xxii (1904), 195–237, p. 201; Jaeger, *op. cit.* (ref. 14), 138; Gerrit Tierie, *Cornelis Drebbel (1572–1633)* (Amsterdam, 1932), 4, 92; F. W. Gibbs, "The furnaces and thermometers of Cornelis Drebbel", *Annals of science*, vi (1948), 32–43; Marie Boas, "Hero's pneumatica: A study of its transmission and influence", *Isis*, xl (1949), 38–48, p. 45; W. E. Knowles Middleton, *A history of the thermometer and its use in meteorology* (Baltimore, 1966), 14–23; and Kirstine Bjerrum Meyer, *Die Entwickelung des Temperaturbegriffs im Laufe der Zeiten* (Braunschweig, 1981), 28. See also the discussion of Jennifer Drake-Brockman, below (ref. 131). For a more recent and sympathetic interpretation of the significance of Drebbel's "weather glass", see Borrelli, *op. cit.* (ref. 16). My argument differs from Borrelli's excellent account in emphasizing the relationships, rather than the contrasts, between such disparate endeavours as mechanics and alchemy.
19. The question is further complicated by the purposeful conflation of the functions of indicating heat and foretelling weather changes, or of what we would call thermoscopes and baroscopes. See, for instance, John Bate, *The mysteryes of nature and art* (London, 1634), 38–39.
20. For this approach to the history of invention, see Lorraine Daston (ed.), *Biographies of scientific objects* (Chicago, 2000).
21. Johann Daniel Major uses this term in *Genius errans sive de ingeniorum in scientiis abusu* (Kiel, 1677), F, for those who observe perpetually moving chemical microcosms. Among these was the famous engineer Drebbel who, said Major, made a simulacrum of the universe moved by a spiritous liquor, through an occult harmony between that spirit and aether.
22. Alan Gabbey, "The mechanical philosophy and its problems: Mechanical explanations, impenetrability, and perpetual motion", *Change and progress in modern science*, ed. by Joseph C. Pitt (Dordrecht, 1985), 9–84.
23. Alan Gabbey, "Between *ars* and *philosophia naturalis*: Reflections on the historiography of early modern mechanics", *Renaissance and revolution: Humanists, scholars, craftsman, and natural philosophers in early modern Europe*, ed. by J. V. Field and Frank A. J. L. James (New York, 1993), 133–45.
24. Jaeger, *op. cit.* (ref. 14), 14–15.
25. Hartlib, *Ephemerides,* Mersenne to Theodore Haack, 18/2/21A–22B, 20 March 1640, *op. cit.* (ref. 17): "I'ay veu le Compendium de Physique de Cornele Drebel, mais cela ne merite pas la reputation, qu'il avoit, estant fort plat".
26. On Severinus, see Jole Shackelford, *A philosophical path for Paracelsian medicine: The ideas, intellectual context, and influence of Petrus Severinus (1540/2–1602)* (Copenhagen, 2004).
27. Massimo Bianchi, "Occulto e manifesto nella medicina del Rinascimento: Jean Fernel e Pietro Severino", *Atti e memorie dell'Accademia Tuscana de Scienze e Lettere, la Colombaria*, xlvii

(1982), 185–248.

28. Sylvain Matton, "Fernel et les alchimistes", *Corpus*, xli (2002), 135–98, and Hiroshi Hirai, "Humanisme, néoplatonism et *Prisca Theologia* dans le concept de semence de Jean Fernel", *Corpus*, xli (2002), 43–70. Alchemical views of native heat are not studied in most treatments of the idea of heat in the history of science, which generally begin with the mechanical philosophy and the idea of the thermometer. See Everett Mendelsohn, *Heat and life: The development of the theory of animal heat* (Cambridge, 1964), and Hasok Chang, *Inventing temperature: Measurement and scientific progress* (Oxford, 2004).
29. Cornelis Drebbel, *Ein kurzer Tractat von der Natur der Elementen* (Leiden, 1608), preface, unpaginated: "wil ich schreiben von den gemeinen Elementen/ wie sie dir best bekant sein/ da mit du das ubrige nemlich die Erde erkennen lernest/ dan die Erde ist nicht so simpel as Feuwer/ Lufft unnd Wasser/ sondern ist der unreine rest/ dan man findet volkomlich vier Elementische Naturen in der Erden/ unnd ihrem gewächs damit wir unser werck volbringen/... wie ich hernach weitlauftiger erzehlen wil/ meinen anfang nemendt von der Schöpfung/ und die selbige an zu deuten."
30. See Johann Jakob Kirstenius's history of element-glasses, *Dissertatio physico-chemica de repraesentatione quatuor elementorum in vitro* (Altdorf, 1746).
31. Libavius, *op. cit.* (ref. 11), 438: "Scire vero debes, lector, *Sedinvogii* scriptum paenè germanum esse *Drebbeliano*. Uterque enim naturam universalem & particularem explicat isto mysterio, & vicissim hoc illâ. Uterque in Elementis eorumque conversione & commistione ponit totum, ignis vocabulo & spiritus, coelum quoque comprehendo. Quod in uno desideras, id fors in altero tibi, si attentus eris, occurret." On Libavius, see Bruce Moran, *Andreas Libavius and the transformation of alchemy: Separating chemical cultures with polemical fire* (Sagamore Beach, MA, 2007).
32. Libavius, *op. cit.* (ref. 11), 441: "Quod attinet ad generationem naturalem mineralium, & vegetabilium, eam similiter explicauit Drebbelius. Uterque quod vidit & iudicauit fieri in vitro hermetico, dum elixyr fermentatur & in aurificum lapidem mutatur, id putavit evenire etiam in caeteris."
33. *Ibid.*: "Fingunt elementa quatuor *proiicientia & stillantia in centrum seu viscera terrae suas virtutes. In centro collocant principium calorificum, seu ignem naturae*, quod calore externo excitatum perpetuo agitetur, & in materiam humidam circumfusam agat."
34. Borrelli, *op. cit.* (ref. 16), 92.
35. Otto Mayr, *The origins of feedback control* (Cambridge, 1970), and Silvio Bedini, "Role of the automata in the history of technology", in his *Patrons, artisans and instruments of science, 1600–1750* (Brookfield, 1999).
36. Augustus Kuffler, *A very good collection of approved receipts of chymical operations collected by Augustus Kuffeler and Charles Ferrers phylchimist,* Cambridge University Library MS Ll.5.8, 169–70.
37. Cornelis Drebbel, *Wonder-vondt van de eeuwighe beweging h ... hier is oock noch de getuyghnis/ die Cicero/Claudianus/en Lactantius/ gheven van de eeuwige beweging h/ die Archimedes gevonden soude hebben* (Alkmaar, 1607), unpaginated: "in summa wat voor een tijdt ghemaeckt can werden, door dalent gewicht, of door springh-veeren, door loopende wateren, door wint, oft door vier, dat can ghemaeckt worden door dese kennis, voor eeuwelijck."
38. Johann Bohn, "de Igne", *Dissertationes chymico-physicae* (Leipzig, 1685), thesis 29. For Bohn, see Bruce Moran, *Distilling knowledge* (Cambridge, MA, 2005), 124–6.
39. Heinrich Nollius, *Sanctuarium naturae* (Frankfurt, 1619), 113–14.
40. See Schagen's preface, *Wonder-vondt* (ref. 37): "Soo dese wetenschap onder de Sterkondigers ghemeen was soo en soudemen niet behoeven soo veel stellingen en rekeningh der Planeten en ander Sterren maer de Ster-konst soude licht zijn en Copernicus soude bloeyen. Want die bewijst (met reden) dat het Aerdtrijck alle 24. uren ront om gaet: Maer desen Alckmaersche Philosooph can 't selfde niet alleen met reden maer oock met levendige Instrumenten bewijsen."

Francis Bacon also, in *Of the advancement and proficiencie of learning* (London, 1640), 146–7, argued that astronomy currently only saved appearances through mathematical observations and demonstrations rather than showing the true causes of things. It was thus to be placed among the lowly mathematical arts, "not without great diminution of the Dignity thereof; seeing it ought rather (if it would maintaine its own right) be constitute a branch, & the most principall of Naturall Philosophy". Whoever would observe "the appetencies of matter, and the most universall Passions (which in either Globe are exceeding Potent, and transverberate the universall nature of things)" would discover the true "Living Astronomy".

41. A number of these sources were published alongside Drebbel's letter to King James I in his *Wonder-vondt* (ref. 37).
42. Drebbel, *Wonder-vondt*, unpaginated.
43. Olaus Borrichius, *Itinerarium 1660–1665*, ii (London, 1983), 166: "Perpetuum mobile Drebbelii se vidisse tradit (forsan ex Mercurio) in vitro cum horologio, ita magneticum ut acus horologii, si propter nebulas sol per duas horas non conspiceretur, adveniente sole momento se transferret acus ex: gr: ab horâ XII ad IIdam." See also *Journal tenu par Isaac Beeckman* (ref. 13), iii, 302.
44. Drebbel, *Wonder-vondt* (ref. 37), unpaginated: "soo hangh alsoo/ in een besloten glas/ de Aerde in't midden van't Water/ en het Water in't midden van de Lucht/ ende de Lucht in't midden van't Vier/ den een den anderen omvangende/ en haer selven soo ront makende/ als eenigh dingh op die Werelt/ sser wonderlijck en ghenuechlijck om sien. Oft ter contrarie/ hangh die lucht in't midden van't Water/ so ront als een cloot/ en het Water in't midden van de Aerde/ den een den anderen omvangende ghelijck wy sien doen de Lucht den Aerdtbodem." For the view of Drebbel's cosmoscope as a chemical microcosm, see Major, *op. cit.* (ref. 21); Nollius, *op. cit.* (ref. 39), 152; Athanasius Kircher, *Magnes* (Rome, 1641), 607; Petrus Servius, *Dissertatio de unguento armario* (Rome, 1642), 57; J. J. W. Dobrzensky, *Nova, et amaenior de admirando fontivm genio ... philosophia* (Ferrara, 1659), 80; *et alia.*
45. Allen Debus, "Motion in the chemical texts of the Renaissance", *Isis*, lxiv (1973), 4–17.
46. Rosalie Colie, "Cornelis Drebbel and Salomon de Caus: Two Jacobean models for Salomon's house", *Huntington Library quarterly*, xviii (1954), 245–69, and Francis Bacon, *Instauratio magna, Part 3*, ed. by Graham Rees and Maria Wakely (New York, 2007).
47. *Ibid*., 304.
48. Robert Fludd, *Mosaicall philosophy* (London, 1659), 3. See Fludd, *Utriusque cosmi historia* (Frankfurt, 1617–21), Book 1, 30–32; Book 7, 204, and also *Tractatus secundus*, Part Seven, Book Three, 469.
49. Bate, *op. cit.* (ref. 19), unpaginated preface. William Eamon, *Science and the secrets of nature: Books of secrets in medieval and early modern culture* (Princeton, 1994), 308.
50. Kircher, *op. cit.* (ref. 44), 607–12.
51. *Ibid*., 587.
52. *Ibid*., 588.
53. Nicholas Cabeus, S.J., *Philosophia magnetica* (Cologne, 1629), 36.
54. See for example, Heinrich Schuler, *Methodus und principia aller wasserkünste* (Geraw an der Slier, 1622), 21. See also Johann Staricius, *Heldenschatz* (Frankfurt, 1615), 9–14. No perpetual motion fitting this description appears in the Prague 1607–11 inventory of the *Kunstkammer.* R. Bauer and H. Haupt, "Das kunstkammerinventar Kaiser Rudolfs II, 1607–1611", *Jahrbuch der Kunsthistorischen Sammlungen in Wien*, lxxii (1976), entire volume. However, Phillip Hainhofer and Martin Zeiller described a "perpetuum mobile, welches in ainem gläserinen Ring ascendiert vnd descendiert" held in the Dresden *Kunstkammer.* See Oscar Doering, *Des Augsburger Patriciers Philip Hainhofer reisen nach Innsbruck und Dresden* (Vienna, 1901), 167, and Martin Zeiller, *Handbuch von allerley nützlichen Erinneringen* (Ulm, 1655), 490. Wilhelm Lang identified it

as Drebbel's perpetual motion in a 1654 letter to Olaus Worm: *Olai Wormii et ad eum doctorum virorum epistolae tomus II* (Copenhagen, 1751), 1085–6.

55. Cabeus, *op. cit.* (ref. 53), 36.
56. Eileen Reeves, "Occult sympathies and antipathies: The case of early modern magnetism", *Wissensideale und Wissenskulturen in der frühen Neuzeit*, ed. by Wolfgang Detel and Claus Zittel (Berlin, 2002), 97–114.
57. Heinrich Khunrath, *Magnesia catholica philosophorum* (Magdeburg, 1599); Betty Jo Teeter Dobbs, *The foundations of Newton's alchemy* (Cambridge, 1975), 160; and the discussion of Sendivogius below.
58. Johann Hartmann, *Disputationes chymico-medicae* (Marburg, 1611), reprinted in 1614 and in Hartmann's *Opera omnia medico-chymica* (Frankfurt, 1684, 1690, 1694). For the importance of this collection, see Debus, *op. cit.* (ref. 5).
59. Bruce Moran, *The alchemical world of the German court: Occult philosophy and chemical medicine in the circle of Moritz of Hessen (1572–1632)* (Stuttgart, 1991), 55–56.
60. Hartmann, "Disputatio hermetica", *Disputationes chymico-medicae* (Marburg, 1611), 23–35, p. 24.
61. Hartmann, *op. cit.* (ref. 60), 27.
62. *Ibid.*
63. See L. A. Deer, "Academic theories of generation: The contemporaries and successors of Jean Fernel (1497–1558)", Ph.D. thesis, Warburg Institute, University of London, 1980, 393–4.
64. Johann Hartmann,"Contradictiones apparentes quatuor, in quibus praecipuae utriusque medicinae dogmaticae nempe, & hermeticae hypotheis, & rationes breviter recensentur, excutiuntur, & conciliantur", *Disputationes chymico-medicae* (Marburg, 1611), 108–66. Numbers below refer to thesis numbers.
65. *Ibid.*, 24.
66. *Ibid.*, 25–26.
67. *Ibid.*, 27.
68. Like lists of *quaestiones* accompanying other dissertations, the *epithemata* appear to be points to be taken into account during the dissertation, and were possibly pre-circulated before the dissertation. My special thanks to Kevin Chang for help in understanding the structure of this dissertation.
69. Hartmann, *op. cit.* (ref. 64), 165–6: "Perpetuum mobile Cornelii Drebbel Batavi, quod in Anglia visitur, sempiternos siderum motus, temporumque vicissitudines, & Oceani reciprocationes ad momenta & puncta in aevum repraesentans: ut & organum ejusdem Musicum coelo sereno suavissimam harmoniam nullo digitulo tactum edens, nubilo silens, ab Anima mundi, seu spiritu universi, astrali insensibili in sphaeram & instrumentum illud artificio Chymico magnetica vi attracto, infuso, & concluso moveri uri, rotari, & coninuari vero consentaneum est."
70. Burggrav termed himself a "domesticus" of Hartmann in the preface to Clodius, *Officina medica* (Frankfurt, 1620). There he praised his patrons for appointing Johann Hartmann to teach chymistry at Marburg. He also referred to his travels in England, France, Central Europe, and the Netherlands. Burggrav's treatise on the distillation of oils was printed in Hartmann's *Practice of chymistry* in 1634, while the 1623 *Introduction to the vital philosophy* has been variously ascribed to Burggrav and to Hartmann.
71. See Burggrav's preface to Drebbel, *op. cit.* (ref. 13), A2v. Burggrav issued both a German and an independent Latin translation of Drebbel's works in 1628, and also claimed the anonymously-edited first extant edition (printed in German in 1608) as his.
72. For instance, Vranckheim defended Jacob Metius as the inventor of the telescope against Galileo. See Vranckheim, "Epistola", Johann Ernst Burggrav, *Biolychnium* (Franeker, 1611), 49–80, pp. 53–54. Interestingly, Vranckheim's letter is dated December 1609, although he refers to Galileo's

Sidereus nuncius (not published until 1610). Vranckheim wrote his letter a few month's after earning his degree, signing it Dec. 1609 at Padua. Burggrav referred to the perpetual motion and the letter from his friend also in his work on "electrical weapons", *Achilles panoplos redivivus; seu panoplia physico-vulcania* (Amsterdam, [1612]), 55.

73. See, for instance, John Webster, *The displaying of supposed witchcraft* (London, 1677), 269.
74. Vranckheim began his career as Constantijn L'empereur's private tutor until 1608. He then went abroad to study at the expense of his patron, and defended theses in 1609 at Basel and Marburg. Vranckheim returned to Zutphen where he was appointed rector of the Latin school. See Peter T. Van Rooden's *Theology, biblical scholarship and rabbinical studies in the seventeenth century* (Leiden, 1989), 21, and Friedrich Nettesheim's *Geschichte der Schulen im alten herzogthum Geldern* (Düsseldorf, 1881), 331. Johannes Roberti published his 1616 letter to Arnold van Boecop, S.J., renouncing his faith and his magical views. See Roberti, "Goclenius heautontimorumenos", *Theatrum sympatheticum* (Nürnberg, 1662), 369–73.
75. Vranckheim, *op. cit.* (ref. 72), 55: "scintillula Animae Mundi, quod ajunt, Magnetica, seu Astrali rerum omnium Spiritu insensibili, Harmonica superiorum et inferiorum, id est, Majoris, Minorisque, Mundi conspiratione: qua & aquas illas Globo vitreo Sphaeram illam inclusam ambiente, ut scribis, inditas, Aeviterno Motu, Motore Vero Inferno, An Externo, an Utroque? certis statisque temporibus credo suis agi incrementis progressionibus, regressionibus, Harmonica cum Oceani aestu Sympathia continenti ad momenta & puncta etiam accessu, recessu." *Cf.* ref. 59.
76. *Ibid.*, 56.
77. *Ibid.*, 56–57.
78. *Introductio in vitalem philosophiam* (Frankfurt, [1623] 1645), 4.
79. Daniel Sennert, *Chymicorum cum aristotelicis et galenicis consensu ac dissensu liber* (Wittenberg, 1619), 148–9.
80. *Ibid.*, 149. Compare Hartmann, *op. cit.* (ref. 60), 26–27.
81. Andreas Libavius, "De extract. essent. & elixyr. lib IIX", *Syntagma arcanorum chymicorum* (Frankfurt, 1611), 363–480, p. 392.
82. *Ibid.*
83. Libavius, *op. cit.* (ref. 81), 469.
84. Michael Maier, *Verum inventum* (Frankfurt, 1619), 95–97. Drebbel, *Wonder-vondt* (ref. 37), unpaginated: "wir sehen wan der Saltpeter gebrochen wirdt durch das Feuwer unnd also verandert in die natur des Lüffts." On Drebbel and saltpetre, see Zbigniew Szydlo, *Water which does not wet hands: The alchemy of Michael Sendivogius* (Warsaw, 1994).
85. Frances Willmoth, "Mathematical sciences and military technology: The Ordnance Office in the reign of Charles II", *Renaissance and revolution*, ed. by J. V. Field (Cambridge, 1993), 117–32. Kenelm Digby, *Two treatises in the one of which the nature of bodies, in the other, the nature of mans soule is looked into in way of discovery of the immortality of reasonable soules* (Paris, 1644), 220. Some of Heydon's alchemical correspondence is preserved in the U.K. National Archives. See State Papers 16/373/37, 16/374/38 and 55, 16/397/48r–v.
86. Moran, *op. cit.* (ref. 31), 200–1.
87. Andreas Libavius, "De igne naturae", *Syntagma arcanorum chymicorum ... tomus secundus* (Frankfurt, 1613), 1–120, p. 102.
88. *Ibid.*
89. Libavius, *op. cit.* (ref. 11), 365.
90. *Ibid.*, 370.
91. *Ibid.*, 443 and 450.
92. *Ibid.*, 440–1.
93. On Libavius and the spirit of the world, see Moran, *op. cit.* (ref. 31), 286.

94. Libavius, *op. cit.* (ref. 89), 362.
95. Andreas Libavius, *Probabilis investigatio caussarum physicarum, aliarumque globi Archimedaei novi & instrumenti musici per se absque evidente motore mobilium* (Coburg, 1612), thesis 21. Numbers below refer to theses or questions. "Modus dicitur insensibilis & astralis: artificium modi, chymicum: Forma & actus, attractio magnetica, infusio, conclusio, motus, rotatio, continuatio, quod cum vero pronuncietur consentaneum." *Cf.* ref. 59.
96. *Ibid.*, theses 24–25.
97. *Ibid.*, thesis 30.
98. *Ibid.*, thesis 37.
99. *Ibid.*, questions 5–6.
100. Reprinted in Johann Hartmann, *Disputationes chymico-medicae* (Marburg, 1614). See Moran, *op. cit.* (ref. 31), 235–6.
101. Andreas Libavius, "De philosophia vivente", *Examen philosophiae novae* (Frankfurt, 1615), 88.
102. *Ibid.*, 89.
103. *Ibid.*, 126.
104. Andreas Libavius, "Exercitatio paracelsica nova de notandis excerpto fraternitatis de rosea cruce", *Examen philosophiae novae* (Frankfurt, 1615), 262–306, p. 264.
105. Johann Hartmann, *Fama fraternitates* (Kassell, 1614), 107.
106. Libavius, *op. cit.* (ref. 104), 271.
107. *Ibid.*, 277.
108. *Ibid.*, 271.
109. *Ibid.*, 278.
110. *Ibid.*, 285.
111. For Libavius as a moderate Semi-Ramist, see Moran, *op. cit.* (ref. 31), 20–21.
112. Hartmann, *op. cit.* (ref. 100), Sylvain Matton, "L'alchimie chez les ramistes et semi-ramistes", *Argumentation*, v (1991), 408–13, and Moran, *op. cit.* (ref. 31).
113. Howard Hotson, *Commonplace learning: Ramism and its German ramifications, 1543–1630* (New York, 2007), 121.
114. Johann Heinrich Alsted, *Compendium philosophicum* (Herborn, 1626), 22. Johann Sibertus Küffler, *Disputatio physica de corporis naturalis generalibus principiis et affectionibus* (Herborn, 1615). I am grateful to Howard Hotson for the reference to Küffler's dissertation.
115. Johann Heinrich Alsted, *Cursus philosophici encyclopædia libris XXVII* (Herborn, 1620), 982.
116. Alsted *op. cit.* (ref. 114), 288. "... admoneo, ne vel cogitatione sejungatis mobile perpetuam mechanicum à mobili perpetuo physico." For Alsted's definition of soul and entelechy, see *Compendium philosophicum,* 191.
117. D. J. B., "Spiritu mundi positiones aliquot", reprinted from the *Ephemerides* of the Holy Roman Imperial Academy in Manget's *Bibliotheca chemica curiosa*, ii (Geneva, 1702), 875–7, p. 877.
118. Hotson, *op. cit.* (ref. 113), 33.
119. On Nollius, see Moran, *op. cit.* (ref. 59), 122–9, and Carlos Gilly, "Das bekenntnis zur gnosis von Paracelsus bis auf die schüler Jacob Böhmes", *From Poimandres to Jacob Böhme: Gnosis, hermetism and the Christian tradition*, ed. by R. van den Broek and Cis van Heertum (Amsterdam, 2000), 385–426. Nollius defended a thesis in Marburg under the aegis of Harmann's son-in-law, Heinrich Petraeus. See Heinrich Nollius, "De Methodo medendi Hermetica", *Agonismata medica Marpurgensia* (Marburg, 1619), 346–353. Alsted, *op. cit.* (ref. 115), 116, 451.
120. Nollius, *op. cit.* (ref. 39), 11, 61, 112, 126, 148, 152, 236, 279, 752. Szydlo, *op. cit.* (ref. 84), discussed Nollius's citations of Sendivogius and mentioned his citations of Drebbel.
121. *Ibid.*, 152.

122. *Ibid.*, 61.
123. *Ibid.*, 684. Drebbel, *op. cit.* (ref. 29), chap. 10, unpaginated.
124. On Mögling, see Moran, *op. cit.* (ref. 59), 172, and Ulrich Neumann, "'Olim, da die Rosen Creutzerey noch florirt, Theophilus Schweighart genant': Wilhelm Schickards Freund und Briefpartner Daniel Mögling (1596–1635)", *Zum 400. geburtstag von Wilhelm Schickard*, ed. by Friedrich Seck (Sigmaringen, 1995), 93–116.
125. Valerius Saledinus [Daniel Mögling], *Perpetuum mobile* (Frankfurt, 1625), 26.
126. *Ibid.*, 40: "unser Invention mehr auss naturlichen Magischen ... als Mechanicis Staticisque Fundamentis ursprunglichen herreichet." 48: "Das Principalwerck aber/ und erste Bewegung muss (wie gemeldet) ex Magia Naturali hergenommen werden." 52–55.
127. Theophilus Schweighart [Daniel Mögling], *Prodromus rhodo-stauroticus* (Prague, [1620]), unpaginated: "müssen wir heirvon die jenige Philosophos ersuchen/welche solches perpetuum mobile selbsten zugerichtet/ und in dessen Zurichtung nicht allein die Erschaffung der Welt/ sondern in dem allbereit zugerichteten/ den Lauff der Gestirn/ der Elementen unnd aller Ding Natur und Eygenschafft compendiose, augenscheinlich vorzeigen können."
128. Libavius, *op. cit.* (ref. 95), *Quaestione* 2.
129. Domenico Bertoloni Meli, *Thinking with objects: The transformation of mechanics in the seventeenth century* (Baltimore, 2006).
130. Gabbey, *op. cit.* (ref. 22), reviewed some of the contradictions inherent in this re-interpretation. See also Dennis Des Chene, *Spirits and clocks: Machine and organism in Descartes* (Ithaca, 2001), 14, and Garber, *op. cit.* (ref. 1), 414. For the importance of Fernel to Descartes, see Vincent Aucante, "Descartes's experimental method and the generation of animals", *The problem of animal generation in early modern philosophy*, ed. by Justin E. H. Smith (Cambridge, 2006), 65–79, p. 70.
131. Jennifer Drake-Brockman, "The perpetuum mobile of Cornelis Drebbel", *Learning, language, and invention: Essays presented to Francis Maddison*, ed. by Willem Dirk Hackmann and Anthony John Turner (Brookfield, VT, 1994), 124–47, p. 147.
132. *Cf.* Chang, *op. cit.* (ref. 28), 8.
133. Balthasar de Monconys, *Iovrnal des voyages de Monsievr de Monconys*, ii (Lyons, 1666), 54, and Hebbel E. Hoff and L. A. Geddes, "The beginnings of graphic recording", *Isis*, liii (1962), 287–324.
134. Lorraine Daston, "On scientific observation", *Isis*, xcix (2008), 97–110, p. 102.
135. Robert Boyle, *Works of Boyle*, xiii, ed. by Michael Hunter (London, 2000), 480–2.
136. *Ibid.*, 298.
137. Newman, *op. cit.* (ref. 1), 175–89, has related Boyle's use of the term 'mechanical' to machines that are no more than the sum of their parts, and whose parts could be made of any substance. Others, by contrast, saw Drebbel's machine as more than the sum of its parts, and/or as a physical and chemical motion relying on specific natures rather than the arrangement of parts. J. J. Becher, *De nova temporis dimetiendi ratione et accurata horologiorum constructione, theoria & experientia* (London, 1680) 4, 15–16, and G. W. Leibniz, Landesbibliothek Hannover LH035, 15, 06, 46r–47r, and published online by the Berlin-Brandenburgische Akademie der Wissenschaften, http://www.leibniz-edition.de/, cited July 29, 2008. *Cf.* Bennett, *op. cit.* (ref. 6, 2006), 680–1, for whom the use of the pendulum clock in the search for longitude supported the idea that its motion was natural.
138. G. W. Leibniz, "Mémoire pour des personnes esclairées et de bonne intention", *Politische schriften*, iv, ed. by Friedrich Beiderbec *et al.* (Berlin, 2001), 619.