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BETWEEN DESCARTES AND BOYLE: BURCHARD DE VOLDER'S EXPERIMENTAL LECTURES AT LEIDEN, 1676-1678

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1. Introduction

Burchard de Volder (1643-1709), professor of philosophy and mathematics at Leiden from 1670 to 1705, has long been studied from a variety of perspectives. His significance in the history of philosophy and science has been recognized, if only for his role as founder of the Leiden experimental *theatrum* in 1675.[1] He has been viewed as a 'discontent' Cartesian who allegedly converted to Newtonianism.[2] He has also attracted attention as a correspondent of Leibniz (1646-1716).[3] Moreover, historians have debated his supposed 'crypto-Spinozism'.[4] As Tammy Nyden has put it,

> what makes de Volder an interesting and valuable object of study is precisely

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[1] This has been analysed in De Pater, "Experimental Physics," though with no attention for De Volder's overall natural-philosophical ideas.

[2] Sassen, "The Intellectual Climate." This claim has been later disproved: see Krop, "Medicine and Philosophy"; see also Ruestow, *Physics*, 89-112.

[3] Russell, "The Correspondence between Leibniz and De Volder"; Hall, "Further Newton Correspondence"; Lodge, *The Leibniz-De Volder Correspondence*; Rey, "L'ambivalence de la notion d'action" (first and second parts).

[4] Sustained in Klever, "Burchardus de Volder"; criticized in Lodge, "Burchard de Volder."

> that he does not fit neatly into the categories of Cartesian, Newtonian, and Spinozist, or perhaps we should say, his case indicates how untidy these categories actually were in the seventeenth century.[5]

In particular, it is his peculiar approach to teaching a natural philosophy essentially inspired by the ideas of René Descartes (1656-1650) by means of an experimental agenda based on that of Robert Boyle (1627-1691) that renders De Volder an interesting figure for understanding how Cartesianism was disseminated in the course of the seventeenth century. He figures as part of what has recently been described as 'Cartesian Empiricism'.[6] Though experiments played an important role in the development of the ideas of Descartes himself, he did not set forth an experimental agenda. This was developed later in the seventeenth century, in particular in France, by Robert Desgabets (1610-1678), Jacques Rohault (1618-1672), and Pierre-Sylvain Régis (1631-1707).[7] In the Netherlands – the first country in which Cartesianism entered at the university – it was Henricus Regius (1598-1679) who first developed an empirical approach to Cartesianism, rejecting innatism as a source of knowledge. However, only De Volder eventually provided a teaching by means of experiments, based on sources other than Descartes yet aimed at demonstrating the validity of his philosophy, which De Volder continued to teach in the same years, by dictating commentaries (*dictata*) on his *Principles of Philosophy* (1644).

In fact, given the lack of any systematic treatise by De Volder, as his printed works were limited to academic orations and disputations,[8] in order to capture his thought one needs to look at sources different from the ones usually considered by historians – learned

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[5] Nyden, "De Volder's Cartesian Physics," 228-229. Nyden, in particular, has analysed De Volder's epistemology.

[6] Dobre and Nyden, *Cartesian Empiricisms*.

[7] Roux, "Was There a Cartesian Experimentalism in 1660s France?"

[8] Wiesenfeldt, "Academic Writings."

correspondences, printed texts, etc. – and to focus instead on the specific types of document that provide us with insights into the contents of his academic teaching: students' notebooks and academic textual commentaries on the works of Descartes, extant to us as handwritten *dictata*. By considering such sources, in this chapter, I shed light on the ways Cartesian ideas were taught and discussed at Leiden in the last quarter of the seventeenth century, and how these became entangled with the early modern experimental philosophy. After an overview of De Volder's life and works (section 2), I will detail and discuss a selection of contents of his experimental lectures taking place at Leiden in 1676-1678 (based mostly on Boyle, though with important references to Simon Stevin, 1548-1620) (section 3), and I will analyse the contents of his theoretical physics (based mostly on Descartes and on Archimedes' theory of floatation) (section 4). I will discuss how his experimental and theoretical physics interrelated, by considering De Volder's explanation of the lack of the sensation of pressure under water, for which he relied mostly on Descartes and on a Cartesian interpretation of the theory of floatation of Archimedes (section 5). As a conclusion, I argue that De Volder failed to capture an essential conceptual shift in the treatment of hydraulic and pneumatic pressure in the seventeenth century: namely, the passage, highlighted by Alan Chalmers, from a 'common' interpretation of pressure to a more 'technical' meaning, where the "former relates to forces on bounding surfaces between media whereas the latter refers to forces within the body of media."[9] This ultimately led to a divergence between De Volder's experimental and theoretical physics.

2. De Volder's life and works

Born in Amsterdam on 26 July 1643, De Volder studied philosophy at the Amsterdam

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[9] Chalmers, *One Hundred Years of Pressure*, 6.

Athenaeum illustre from 1657 onwards, following the lectures of Arnold Senguerd (1610-1667) and Alexander de le Bie (1623-1690).[10] Subsequently, he matriculated at the University of Utrecht, graduating on 18 October 1660 as *magister artium* under the Cartesian professor Johannes de Bruyn (1620-1675). Then, he moved to the University of Leiden, where he graduated in medicine with a disputation *On Nature* (3 July 1664), dedicated to Franciscus Sylvius (1614-1672) and Johannes Hudde (1628-1704). After some years spent in Amsterdam as town physician, he was able to obtain a chair in logic at the University of Leiden in September 1670, through the recommendation of Hudde himself. De Volder started his teaching activities by lecturing on the logic of Franco Burgersdijk (1590-1635), and, after a few weeks, was allowed also to teach natural philosophy.[11] At this point, he had aligned himself with the ‘Cartesian faction’ at Leiden, of which, after the departure of Johannes de Raey (1620/1622-1702) and the death in 1669 of Arnold Geulincx (b. 1624), he was a representative alongside Theodoor Craanen (ca. 1633-1688) (appointed in June 1670) and the theologians Christoph Wittich (1625-1687) and Abraham Heidanus (1597-1678). It was with Wittich and Heidanus that De Volder was actively involved in the defence of Cartesianism following the departure from the University of the Aristotelian philosopher Gerard de Vries (1648-1705) in 1674, as a consequence of student disturbances during his lessons and disputations.[12] Indeed, Jean Le Clerc (1657-1736) reported that De Volder, in a now lost manuscript, explained how he himself had attempted, in June 1674, to convince the Grand Pensionary of Holland, Gaspar Fagel (1634-1688), that Cartesian philosophy did not pose any danger; and that, to the contrary,

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[10] Biographical information on De Volder is mostly provided in Le Clerc, “ĳ loge”; Gronovius, *Burcheri de Volder laudatio*; Niceron, “Burcher de Volder.”

[11] Concerning the practice of teaching Burgersdijk’s work at Leiden, see the chapters by Hotson and Cellamare in this volume.

[12] Concerning Craanen and De Vries’s tumultuous departure from Leiden, see Cellamare’s chapter in this volume. Concerning De Vries’s later activity and position concerning Cartesianism, see Garber’s chapter in this volume.

it had already inspired learned institutions such as the Royal Society.[13]

Between July and August of the same year, provided with a presentation letter by Philipp van Limborch (1633-1712), De Volder travelled to England, where he visited Cambridge and met Isaac Newton (1642-1726).[14] Having returned to Leiden, in December 1674, he asked the Curators of Leiden University to fund the establishment of a *Theatrum physicum*, or *Auditorium philosophiae experimentalis*, which was to be a classroom wherein "to teach and to point, through experiments, to the truth and the certainty of the principles and doctrines that the students had learnt in *physica theoretica*."[15] The *theatrum*, whose main tool was an air-pump built by Samuel van Musschenbroek (1640-1681), based on the model by Robert Hooke (1635-1703) and now extant at the Boerhaave Museum at Leiden,[16] opened the following year.[17] In 1674, De Volder also commenced his activities as a full-fledged academic philosopher, presiding over a series of disputations: in particular, his *On the Principles of Natural Things* (1674-1676), which is a defence of the use of the ideas of matter, movement, size, figure and disposition as first principles in natural philosophy; his *On the Weight of the Air* (1676-1678), giving some insights into his experimental lectures; his *Against the Atheists* (1680-1681), providing Cartesian-inspired demonstrations of the existence of God; and his *Philosophical Exercises* (1690-1693), a criticism of the *Censorship of Cartesian Philosophy* (1689) of Pierre-Daniel Huet (1630-

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[13] Le Clerc, "ÿ loge," 356-359. On the 'Cartesian' character of the Royal Society, see Jalobeanu, "The Cartesians of the Royal Society." In 1676 De Volder also partially authored a defence of Cartesian theses which appeared as Heidanus et al., *Consideratien*, and which caused the dismissal of Heidanus – the only official author of the book – from his academic post.

[14] See Des Amorie van der Hoeven, "De Philippo a Limborch," 39; Hall, "Further Newton Correspondence."

[15] "[…] by experimenten moghten werden gedoceert en aengewesen de waerheyt ende seekerheyt van die stellingen ende leeren, die in Physica theoretica de studenten werden voorgehouden," Molhuysen, *Bronnen*, vol. 3, 298. Unless taken from an already translated primary source, all translations are by the author.

[16] De Clercq, *The Leiden Cabinet*, 67-68.

[17] Molhuysen, *Bronnen*, vol. 3, 301-302. Experimental lectures were nonetheless already being given, from 1672, at Altdorf University by Johann Christoph Sturm.

1721). In the meantime, he also assumed the chair of mathematics and the directorship of the Leiden astronomical observatory (1682). Upon its publication, he carefully studied Newton’s *Mathematical Principles of Natural Philosophy* (1687), finding its contents *veritables* and sharing insights on his reading of Newton’s text with Christiaan Huygens (1629-1695).[18] The late 1690s saw De Volder distance himself from Cartesianism, when, according to Le Clerc, he became dissatisfied with teaching Descartes’s *Meditations on First Philosophy* (1641) and with Rohault’s *Treatise on Physics* (1671).[19] He started a long correspondence (1698-1706) with Leibniz, from whom he requested a demonstration of the activity of material substance, deeming the recourse to God as a ‘universal mover’, typical of Descartes and his followers, “not worthy of a philosopher.”[20] Eventually, he retired from Academic teaching in 1705, leaving a well-equipped academic *theatrum*, and died in 1709.[21]

While it is clear that De Volder defended Cartesian ideas during his career and at least into the 1690s, it is less clear how these relate to his experimental lectures, which started in the mid-1670s.[22] On these, indeed, De Volder provided some evidence in his aforementioned *On the Weight of the Air*, which offers only a limited view of the actual contents of his experimental teaching, however, being a text (as I will show in section 4) dedicated mostly to the natural-philosophical interpretation of a limited number of experimental observations. More insights are afforded, on the other hand, by a document

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[18] Le Clerc, “ĳ loge,” 379-380.

[19] “ĳ loge,” 398. There are traces of a lost series of academic *dictata* of De Volder on the *Treatise on Physics* of Rohault, dated 1698 and 1699, listed in the auction catalogue of a private library of 1752: “Annotata in Jacobi Rohaulti, Tractatum physicum, a clariss. et nobil. Professore Burchero de Volder, 1698. MS,” and “Annotata in Rohaultii, tertiam Partem de rebus terrestribus a clar. et nobili Professore Buchero de Volder, A° 1699,” Scheurleer, *Bibliotheca Martiniana*, 116 and 427.

[20] Leibniz to De Volder, 19 November 1703, in Lodge, *The Leibniz-De Volder Correspondence*, 279.

[21] An inventory of the instruments of the *theatrum* is given in Molhuysen, *Bronnen*, vol. 4, 104*.

[22] As to De Volder’s Cartesianism, especially in metaphysics, see Strazzoni, *Dutch Cartesianism*, chapter 6.

first brought to attention by Adriaan de Hoog in his unpublished doctoral dissertation (1974), and then discussed by Gerhard Wiesenfeldt (2002), who has considered it in the context of the history of experimental practices at Leiden, and which I aim to discuss in the light of De Volder's broader natural-philosophical positions.[23] The handwritten report, namely, of De Volder's experimental lectures in the years 1676-1677, was provided by an English student of his, Christopher Love Morley (1645/1646-1702) under the title *Experimenta philosophica naturalia*. Written mostly in English and containing relatively free annotations on lectures rather than literal *dictata*, this notebook – together with many other reports by Morley, who collected some 40 volumes of lecture notes, mostly on chemistry and medicine – can be accessed at the British Library.[24] Moreover, a further report by a student of De Volder, Hermann Lufneu (1657-1744), appeared in the *Nouvelles de la République des Lettres* in 1685-1687, providing evidence of De Volder's activities for the years 1677-1678. Additionally, insights into De Volder's explanations of experimental results are provided in his dictated commentaries on Descartes's *Principles of Philosophy*, now extant at various libraries. These are the main sources to be considered in an analysis of De Volder's experimental approach to natural philosophy and its connection with his broader theoretical physics.

3. De Volder's experimental lectures in 1676-1678

Morley's *Experimenta philosophica naturalia* reports 28 experiments which took place from 12 March 1676 to 25 March 1677. For the present purposes, it suffices to consider a few of these experiments. In particular, in experiments 1-2 (the same experiment, repeated once), De Volder made two cylinders of marble, one of which was appended to a support,

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[23] De Hoog, *Some Currents of Thought*; Wiesenfeldt, *Leerer Raum*, 54-64 and 99-132.

[24] Mss. Sloane 1256-1299. Morley also took notes of courses given by Craanen, one of which is considered in this volume by Cellamare.

sticking together at their flat surfaces, in open air (such as in Figure 1, from Morley's notebook, and in Figure 2, from a sale catalogue (1700) of Johannes Joosten van Musschenbroek (1660-1707), successor of Samuel).[25] From here, he appended some weight to the lower cylinder, until they fell apart.[26] The cohesion of bodies along their flat surfaces was described as early as in Lucretius' *On the Nature of Things*.[27] In early modern times, such an experiment was attempted by Boyle and described in his *Defence of the Doctrine Touching the Spring and Weight of the Air* (1662): Boyle, as remarked by De Volder himself, could not, however, append to the cylinders so much weight as De Volder did.[28] In fact, Boyle had attempted such an experiment both in open air and in a vacuum (as in experiment 31 of his *New Experiments Physico-Mechanicall*, 1660), in order to show the role of air pressure in the cohesion of the two pieces of marble (which do not cohere in a vacuum).[29] This was also one of the aims of De Volder in performing the experiment, who however did not perform it in a vacuum, arguing that air pressure kept them together through a dismissal of the idea, to which the Aristotelians (like Gaspar Schott, 1608-1666) usually reverted, that cohesion in situations like this is due to the fear of a vacuum – as in fact it is nonetheless possible to pull the cylinders apart.[30] Also, the experiment served De Volder to shed light on a further phenomenon, namely the lack of the sensation of air pressure or water pressure on our bodies: De Volder argues that we do not feel such a pressure because of its uniformity, as it "compresses equally on all sides."[31] This theory, as I discuss further in section 5, can be traced back to Stevin and

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[25] Figures 1 and 2 are respectively in De Volder, *Experimenta*, 78^v, and Van Musschenbroek, *Descriptio antliae*, plate 3, figure 2.

[26] De Volder, *Experimenta*, 78^r-78^v.

[27] Lucretius, *On the Nature of Things*, I, 384-398; VI, 1087-1089.

[28] De Volder, *Experimenta*, 80^v; Boyle, *A Defence*, 84-86.

[29] Boyle, *New Experiments Physico-Mechanicall*, 229-233.

[30] De Volder, *Experimenta*, 81^r-81^v; Schott, *Mechanica*, 25-26.

[31] De Volder, *Experimenta*, 81^r.

was later embraced by Boyle. It is crucial to a correct understanding of De Volder's approach to hydrostatics as well as of the ways in which his experimental and theoretical physics interrelate, as in commenting upon Descartes's *Principles of Philosophy* he was to criticize it. Moreover, De Volder used the experiment to argue for a theory alternative to Descartes's explanation of cohesion as due to the parts of a body being at rest, which for De Volder has to be rejected, since a hard body can easily be moved without breaking it. Instead, atmospheric pressure is a better cause of cohesion, as maintained also by Boyle in his *History of Fluidity and Firmness* (1661).[32]

Other experiments involve the use of the air pump, e.g., experiment 3, in which one Magdeburg hemisphere (built for De Volder by Samuel van Musschenbroek and now extant at the Boerhaave Museum),[33] closed by a plate, was emptied of air by means of the air pump, and weights were progressively appended to the plate until they were pulled apart. The same weight could be appended to the apparatus when the plate was replaced by a second hemisphere. This is a variant of the demonstrations of Otto von Guericke (1602-1686) with his hemispheres (see Figure 3).[34] It allowed De Volder to show that air "did only press per lineas perpendiculares," as the weight one can append to the lower hemisphere or to the plate depends only on the diameter of the hemisphere itself, not on its volume or external surface.[35] If we want to make sense of this claim (which contradicts his aforementioned statement that water or air "compresses equally on all sides"), we can articulate it as follows: what matters in the cohesion of the two hemispheres is only the pressure exerted perpendicularly with respect to the line of cohesion between the hemisphere and the plate or of the two hemispheres, not the oblique or lateral pressure

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[32] De Volder, *Experimenta*, 81^v-83^r; Boyle, "The History of Fluidity and Firmness," 213. Descartes's theory of cohesion is given in *Principles* II.54-55 and 63.

[33] De Clercq, *The Leiden Cabinet*, 78.

[34] Von Guericke, *Experimenta nova*, 106. See book 3, chapter 25, devoted to such demonstrations.

[35] De Volder, *Experimenta*, 84^r-86^v.

exerted by air. As a matter of fact, not even De Volder himself could ignore the fact that air and water exert a pressure also in oblique directions, and not only in those directions perpendicular to the horizon (as is illustrated by the fact that if one rotates the hemispheres these do not lose their cohesion). However, as I discuss in sections 5 and 6, his strict reliance on an Archimedean model for hydrostatics and pneumatics did not provide him with the conceptual means to account for phenomena like lateral pressure.

Besides experiments involving air-related phenomena, De Volder performed a number of experiments in hydrostatics. In particular, he showed (experiment 23), contrary to the opinion of some Aristotelians (like Schott), that elements gravitate or press on themselves.[36] For instance, that water presses on water is, for him, shown by the fact that when tubes containing different liquids (as oils or mercury) are dipped in a basin containing water, their level will vary in accordance to the depth the tubes reach, i.e. in accordance to the different pressure exerted by water at different levels.[37] This is an experiment certainly drawn from Boyle's *Hydrostatical Paradoxes* (1666), where it is widely treated in Paradox 1.

Moreover, De Volder attempted to demonstrate, in experiment 25, the same tenet illustrated in experiment 3, this time with regard to water. Namely, that "water […] presses only by straight lines, in no way by lateral, transverse, or oblique [lines]." This is shown by a very simple experiment too, namely, by observing that in an inverted U-shaped container, whose arms are different in size (see Figure 4, from Morley's notebook), the water reaches the same level in both arms, even if one of them contains more water.[38] Of course, the way to make sense of De Volder's words is to recognize that the pressure of water depends only on its height, not on its overall quantity and weight: namely, that the

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[36] Schott, *Magia*, vol. 3, 430-438; criticized in Boyle, *Hydrostatical Paradoxes*, Appendix 1.

[37] De Volder, *Experimenta*, 127^{v}-128^{v}.

[38] De Volder, *Experimenta*, 133^{r}-133^{v} (Figure 4 is at 133^{r}).

weight of a certain volume of water has to be differentiated from the pressure it exerts on the bottom of its container.

This principle – the idea that the pressure of water depends only on its height – is instantiated in the so-called ‘hydrostatic paradox’, which is presented by De Volder in the last experiment (28) reported by Morley. Namely, that the pressure exerted by the water in a cylindrical container terminating in a much wider circular base (an inverted-T-shape when viewed side on) is equal to the one exerted by the water filling a cylindrical, not T-shaped, container with a base and height equal to that of the inverted-T-shaped one. De Volder reports that the first systematic treatment of the paradox was by Stevin – who treats the principle as proposition 10 of his *Principles of Hydrostatics* (*De beghinselen des waterwichts*, 1586; later published as *De hydrostatices elementis*, 1605), and that Boyle, who considered it in his *Hydrostatical Paradoxes*, did not accept the experimental evidence given by Stevin therein.[39]

De Volder too attempted to provide an experimental proof of the paradox. It was described by Lufneu in 1685, reporting an experiment he witnessed around 1677-1678 – so this is, in all probability, one following experiment 28 as reported by Morley. De Volder used an instrument of his own devising, then known subsequently as a ‘cylindrum Volderi’ (see Figure 5),[40] which was an improved model of an instrument first theorized by Stevin in his *Preamble to the Practice of Hydrostatics* (*Anvang der waterwichtdaet* or *De initiis praxis hydrostatices*; appended to his *Principles of Hydrostatics*), and then built and used

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[39] De Volder, *Experimenta*, 140^{r}-141^{r}; Stevin, *Hypomnemata mathematica*, 119-121 (I will henceforth refer to the Latin edition); Boyle, *Hydrostatical Paradoxes*, Paradox 6, scholium.

[40] Lufneu, “Memoire communiquø,” 385. In 1687 Lufneu published a defence of the paradox against the criticism of a certain Moşse Pujolas (Fellow of the Royal Society from 1695), providing more details on De Volder’s demonstration: Lufneu, “Røponse.” The ‘cylindrum Volderi’ became one of the items sold by the Musschenbroek workshop at Leiden: see De Clercq, “Exporting Scientific Instruments.”

by Boyle.[41] This instrument was nothing but a cylinder with a much wider circular base (inverted-T-shape when viewed sideways); the base was moveable, i.e., it could be lifted into the larger cylinder, and the top was linked by a chain to the arm of a balance . This allowed the experimenter to measure the pressure exerted by the water in the container – a pressure different from the bare weight of the water contained in it. In turn, De Volder aimed at measuring the upwards pressure exerted by the water from the lower part of the container on the internal surface HMI of the larger, lower section of the container. Therefore, he made this surface adjustable, and measured the upwards pressure by putting weights on it – as Edme Mariotte (ca. 1620-1684) did with a simpler instrument around the same time (first described in 1678).[42] According to Lufneu's account, this experiment – unlike Boyle's – was successful: De Volder, by measuring with the balance the pressure exerted by water, experimentally proved that the pressure on the bottom EF is the same as that exerted by the weight of water filling a cylindrical container with base EF and height EL.[43]

When one looks at the 1705 inventory of the *theatrum*, one can observe that it contains a broader collection, including instruments aimed at showing the rules of motion.[44] In 1676-1678, however, De Volder seems to have focused mostly on hydrostatical and pneumatical questions, certainly under the influence of Boyle. In fact, many of his experiments are nothing but repetitions of those described in Boyle's *New Experiments Physico-Mechanicall* and *Hydrostatical Paradoxes*. Other important sources are Stevin and Von Guericke, while Descartes's theory of cohesion is overtly criticized in experiment 2. De Volder's didactical experimental programme, thus far, was decidedly

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[41] Stevin, *Hypomnemata mathematica*, 147; Boyle, *Hydrostatical Paradoxes*, Paradox 6, scholium.

[42] Du Hamel, *Philosophia vetus et nova*, vol. 3, 415-416.

[43] Lufneu, "Memoire communiquø," 386-387; Boyle, *Hydrostatical Paradoxes*, Paradox 6, scholium.

[44] Molhuysen, *Bronnen*, vol. 4, 104*.

independent from his overt appreciation for, or association with, Cartesianism in the 1670s; not just because he relied on experimental philosophy sources more recent than Descartes (who did not develop a full-fledged experimental programme), but also because he overtly attacked a Cartesian theory in his lectures. In the explanation of the processes underlying water and air pressure, however, he reverted more to Descartes, as I clarify in the next sections.

4. De Volder's **physica theoretica**

In order to shed more light on De Volder's experimental lectures, we need to look at their background, that is to say, at the ways in which these fit with De Volder's *physica theoretica*. These are his "principles and doctrines" which, as he told the Curators of Leiden University, can be taught by the *physica experimentalis*. Such principles can be found, first of all, in his *On the Principles of Natural Things*. The physical principles defended in this series of disputations are nothing but matter and motion, understood in Descartes's terms as extended substance and as the passage of a body from the proximity to one body through to the proximity to another one; to these, the ideas of *situs* (viz. the reciprocal disposition of parts), figure and size are added. For De Volder, these ideas have to be accepted as the first notions in physics since they: (i) are clear and distinct, (ii) are not the effect of any other natural cause, (iii) do not involve the idea of mind, and (iv) can explain every phenomenon.[45] Despite their evident Cartesian overtones, such principles are not traced back to any particular author. In fact, De Volder shows an appreciation for all those "dedicated to corpuscular philosophy, as the Englishmen call it," namely Pierre Gassendi (1592-1655), Francis Bacon (1561-1626), Descartes and Boyle, whose approach De Volder praises as being "mechanical," certainly under the influence of Boyle himself, as De Volder's categorization matches Boyle's idea of "the corpuscularian

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[45] De Volder, *De rerum naturalium principiis*, disputation 14, theses 3-13.

or mechanical philosophy."[46] At the same time, and just like in his *Experimenta* (experiment 2), he criticized Descartes's theory that rest is the cause of cohesion, explaining that this cannot be granted since a solid body can be easily moved.[47] While accepting Cartesian notions as the basis of physics, De Volder thus adopted a liberal approach towards other authors, including Boyle, as well as a 'mechanical' approach to the study of nature.

Such a 'mechanical' approach is particularly evident from his *On the Weight of the Air*. Each of the five disputations of this series has a different aim. In the first, De Volder gives some evidence for the weight or *gravitas* of the air, such as the *esperienza* of Evangelista Torricelli (1608-1647), or the case of the Magdeburg hemispheres – already addressed in his *Experimenta*.[48] Accordingly, De Volder criticizes some straw-man objections, representative of an Aristotelian standpoint, to the idea that air has a weight and it is not an absolutely light body (disputation 3) as well as the idea of the fear of a vacuum (disputation 4). Eventually, in disputation 5, he details his measurement of the weight of a separate volume of air – also described in his *Experimenta* – performed by weighing, on a balance, two cohering hemispheres deprived of air by means of the pump.[49] The natural-philosophical backbone of the disputations, in turn, is presented in disputation 2, in the form of two laws which he draws from the first postulate of hydrostatics set out in Archimedes' *On floating bodies*. Namely:

> the first one is, in each fluid at rest, each surface of the fluid parallel to the

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[46] "Quae principia dudum reiecta nostro demum saeculo in lucem revocarunt Gassendus, Verulamius, Cartesius, Boylaeus, et quantum est ingeniosorum hominum, qui corpusculari, ut Angli vocant, addicti sunt philosophiae," De Volder, *De rerum naturalium principiis*, disputation 3, thesis 5. See also disputation 10, thesis 8: "non possum non laudare mechanicam explicandi rationem, qua per figuram, magnitudinem, et motum rerum explicantur phaenomena." See Boyle, *The Excellency of Theology*, 51.

[47] De Volder, *De rerum naturalium principiis*, disputation 10, thesis 11.

[48] De Volder, *De aþris gravitate*, disputation 1, theses 1-2.

[49] Cf. De Volder, *Experimenta*, 137^{r}-139^{v}.

> horizon is pressed equally. The second one, if each surface of a fluid parallel to the horizon is unequally pressed, the part [which is] more pressed expels that one, which is less pressed.[50]

De Volder overtly uses these laws to explain two main cases: the ‘forced’ immersion of a body lighter than water into a basin full of water, and the cohesion of the Magdeburg hemispheres. In both cases, the water or air which is around such bodies exerts a downwards pressure which, after a sort of upwards turn, presses from below the lower part of the bodies, exactly as in a balance, where the heavier body pushes the lighter one upwards.[51]

This is the same model used by De Volder to explain the hydrostatic paradox, as reported by Lufneu: given Archimedes’ postulate, in a condition of equilibrium each imaginary surface in a volume of water undergoes the same pressure, from above and below. Thus, in Figure 5, the internal surface HMI of the bigger cylinder undergoes, from below, the same pressure underwent by the water at the same level HMI in between the two cylinders. From above, in turn, the water surface HMI in between the two cylinders receives an equal pressure from the water above it (i.e., the portion of water contained in the smaller cylinder), while the internal surface HMI of the bigger cylinder undergoes either an equal pressure from the weights put on it, or, in the case that the cover (lighter than water) is fixed to the bigger cylinder by screws, this counteracts the pressure from the water below it.[52] At this point, there is equilibrium because there is no displacement of

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[50] “Prima sit, in fluido quovis stagnante unamquamque fluidi superficiem horizonti parallelam aequaliter premi. Altera vero, si superficies quaevis fluidi horizonti parallela inaequaliter prematur, partem magis pressam expellere eam, quae premitur minus,” De Volder, *De aþris gravitate*, disputation 2, thesis 2. See Archimedes’ postulate: “the fluid is of such a nature that of the parts of it which are at the same level and adjacent to one another that which is pressed the less is pushed away by that which is pressed the more,” Dijksterhuis, *Archimedes*, 373.

[51] De Volder, *De aþris gravitate*, disputation 2, theses 4-8.

[52] Lufneu, “Memoire communiquø,” 387-388. See also Lufneu, “Røponse,” 242.

water, regardless of its potential causes: either the downwards pressure of the water contained in the smaller cylinder, or the weights put on the upper surface of the bigger cylinder, or the resistance to displacement of such a surface, when it is fixed to the container, while pressed upwards by the water in the bigger cylinder.

5. Why we do not feel pressure under water?

This Archimedean model of floatation is presented by De Volder – in his *On the Weight of the Air* – together with his explanation of the lack of a sensation of pressure under water, which is based on Descartes's explanation. The discussion represents an ideal case-study of De Volder's approach to dealing with different natural-philosophical standpoints. Descartes's explanation is given in the context of his theory of weight, as presented in chapter 11 of his *The World*, and underlying *Principles* IV.20-27. For Descartes, weight is nothing but an effect of the tendency of each part of matter to pursue its movement according to straight lines. In the case of the matter rotating around the centre of the Earth, some parts have more force to pursue such a movement than others, thanks to their extreme speed: these are the particles of subtle or celestial matter, which recede from the centre of the Earth, pushing downwards any other kinds of body, namely visible bodies, or terrestrial matter. The weight of a body composed only of terrestrial matter is therefore equal to the force of 'downwards extrusion' exerted by a volume of subtle matter equal to the volume of such a terrestrial body. However, since there are no volumes of purely homogeneous kinds of matter, what effectively determines the weight of a body on Earth, for instance, a stone in mid-air, is (i) the excess of celestial matter present in a volume of air equal to such a body which would occupy its place in the case of a descent, with respect to the excess of terrestrial matter in the stone with respect to that contained in such a volume of air, plus (ii) the movement of the particles of the air which, being more subtle than those of the stone, behave as if they were parts of celestial matter. If two bodies, therefore, have the same quantities of subtle and terrestrial matter, and their parts of terrestrial matter have the same force, they are simply in equilibrium: it is the excess of one kind of matter over the other that is instrumental in determining the weight of a body in a medium.[53]

This can be rendered in hydrostatic terms. For Descartes, indeed, such a theory of weight explains why, as he put it in *The World*, "a man at the bottom of very deep water does not feel it pressing on his back any more than if he were swimming right on top."[54] Indeed, for Descartes such a man is not pressed by all the water above him, but only by that volume which, in the case of his descent, will fill its place, and with which there is an actual 'contest': in which the lighter part, provided with more force, extrudes the heavier downwards, thereby making a man under water feel a pressure.[55] Or, as he put to Marin Mersenne (1588-1648), a swimmer in the middle of a basin does not feel the pressure of the water above him because, if pressed downwards by this water, a volume of water equal to that of the swimmer would ascend in his place, and would prevent the descent of the water above him. Thus, would this swimmer feel only the pressure of a volume of water which, rising to his place, pushes him downwards. On the contrary, if this swimmer were to be like the stopper in a hole in a basin, with a space without water below, he would feel the pressure of the whole column of water, as in that case, if he would move downwards, the whole column of water will follow him, without other water rising at his place and counterbalancing the descending water.[56] According to Descartes' model there

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[53] For a discussion of Descartes's theory of weight, see Schuster, *Descartes-Agonistes*, 479-495.

[54] Descartes, *The World*, 50.

[55] Descartes, *The World*, 49-50.

[56] Descartes to Mersenne, 16 October 1639, in Descartes, *Oeuvres*, vol. 2, 587-588. This letter would have been available to De Volder in the edition of the correspondence by Claude Clerselier (1614-1684): Descartes, *Lettres*, vol. 2, 183-184.

is no increasing, internal pressure in water in a condition of equilibrium, as all its sub-volumes counterbalance each other. In a condition of equilibrium, in other words, water is weightless on water. This is the tenet Descartes defends in *Principles* IV.26, overtly entitled “why bodies do not gravitate [when] in their natural places.” He maintains that in a bucket “the lower drops of water, or of another liquid, are not pressed upon by the higher ones,” i.e., any “drop of water […] is not pressed upon by the others […] situated above it,” for the reason that

> if these were carried downward, other drops […] [below it] would have to ascend into their place; and since these drops are equally heavy, they hold the former in equilibrium and prevent their descent.[57]

This is nothing more than is seen in an Archimedean model, where different volumes of water counterbalance each other: in Descartes’s interpretation, such an equilibrium leads to a loss of weight of water in water. Or, as he puts it in *Principles* II.56-57 (devoted to the explanation of the behaviour of a solid body immersed in water, and equiponderant with it, as in Figure 6), “the particles of fluids tend to move with equal force in all directions,” and, being constantly in movement (in order for them to constitute a fluid body), they move according to innumerable circular paths, which do not press in one direction more than in another, and allowing an easy displacement of the solid body once their movement is determined in one direction by a small, external force.[58] So far, for Descartes the particles of water exert a pressure in all the directions, though, the whole fluid is in equilibrium as none of the parts exerts a bigger pressure (in any direction) than the other.

Descartes’s explanation of the lack of a sensation of pressure under water was criticized by Boyle in his *Hydrostatical Paradoxes*, a text based on the same Archimedean

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[57] Descartes, *Principles of Philosophy*, 193.

[58] Descartes, *Principles of Philosophy*, 70. Figure 6 is from Descartes, *Principia philosophiae*, 63.

theory of floatation adopted by De Volder.[59] He does so, in Appendix 2 of his treatise, by attacking Descartes's idea that water does not press on water.[60] He refuted this, as De Volder was to do in experiment 23, by showing how the level of certain fluids, contained in tubes dipped in water, varies in accordance with the depth they reach, i.e., in accordance with the varying pressure of water (in Paradox 1). In a nutshell, for Boyle, Descartes's theory of floatation does not allow for an explanation of why a certain fluid is kept at equilibrium with water at different depths, i.e., it is inconsistent with Archimedes' model of floatation.

Hence, Boyle reverts to the explanation for the lack of a sensation of pressure adopted by Stevin, who, in proposition 3 of his *Preamble to the Practice of Hydrostatics*, claims that we do not feel the pressure of water on account of the uniformity with which it presses on all parts of the body (as De Volder claimed in experiments 1-2): so that no part is more dislocated (*luxatur*) by water than any other. Only in the case where a person is positioned above a hole in the water container (like the stopper in a hole in a basin) would such a person feel the pressure of the water, as such a pressure would not be uniform on him or her.[61] This is the same solution adopted by Von Guericke, and partially refined by Boyle by pointing also to the "texture" of the human body, which "is so strong, that, though water be allowed to weigh upon water, yet a diver ought not to be oppressed by it."[62]

As to De Volder, he moves in a limbo between Descartes and Boyle. As seen above, in experiment 23 he overtly criticizes, following Boyle, the idea that water does not press on water. Furthermore, in experiment 2, he adopts an explanation for the lack of a sensation of pressure under water, akin to those of Stevin and Boyle, where he claims

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[59] Boyle, *Hydrostatical Paradoxes*, 8-11.

[60] Boyle, *Hydrostatical Paradoxes*, 229-236.

[61] Stevin, *Hypomnemata mathematica*, 148-149.

[62] Boyle, *Hydrostatical Paradoxes*, 246; Von Guericke, *Experimenta nova*, book 3, chapter 30.

that:

> the compression of the water […] is not felt when we are in a river, or sea, because all the water compresses equally on all sides. But were there in the bottom of the sea a tubulus, hole, or cavity, which had not one drop of water in it, we should feel all the weight of the water then to press, and ponder, upon us, and with huge violence to force us into that hole, whereas were the hole full of water we should feel no such violence forcing us into it.[63]

A Cartesian explanation of the lack of a sensation of pressure under water is, in turn, given by De Volder in his *On the Weight of the Air* (disputation 3), in which he claims that the water ascending in the place occupied by a person who sinks in water counterbalances – as on two plates of a balance – the pressure of the water above that person, constituting a sort of “wall” (*obex*) by which the person is protected.[64] In any case, in his *On the Weight of the Air*, De Volder seems to smooth the edges of his Cartesian positions: while adopting a Cartesian theory of the lack of a sensation of pressure, he confines his overall theory of weight – based on Descartes’s theory – to the corollaries of the disputations, and refrains from discussing the vexed question of whether elements gravitate to elements.[65] As to this, De Volder did not deal, in the text of disputation 1, with the thesis that they do so as a consequence of the idea that air has a weight, and thereby presses on itself, despite Morley in his *Experimenta*, nevertheless reporting this as having been printed.[66]

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[63] De Volder, *Experimenta*, 81^{r}.

[64] De Volder, *De aþris gravitate*, disputation 3, theses 7-8.

[65] De Volder, *De aþris gravitate*, disputation 3, corollary 11, and disputation 4, corollary 7.

[66] In experiment 24 (held on 28 January 1677): “this experiment was […] relating to the former ones, viz. the equiponderosity of material things with water, or rather as Volder printed these days in some theses which he presided, *omnia corpora*, *quae innatant liquori*, *t*[*antu*]*m h*[*ab*]*ent ponderis*, *quantum liquor a corpore suo ex loco expulsus ponderat*. As also this experiment did relate, unto this thesis likewise then printed by him: *aquam*, *et aþrem esse corpora gravia*, *cum r*[*ati*]*o*, *tum exper*[*ienti*]*a docet*, *ac proinde falsum est*, *elementa in suis locis non esse gravia*,”

De Volder’s Cartesian approach is more overtly declared in his commentaries on Descartes’s *Principles of Philosophy*, which are extant to us in the form of handwritten *dictata* to students.[67] De Volder left two different commentaries on Descartes’s *Principles of Philosophy*. One commentary has survived in two copies, one of which is partial and dated 1690 by the copyist, and is extant at The Hague. The other copy is undated, is complete and extant at Hamburg (hereafter: *Notulae*). The original redaction of this commentary, however, can be traced back to before or around 1673, because it contains a wrong quantification of centrifugal force.[68] In turn, another commentary – which has survived in a much greater number of undated copies, one of which is also extant at Hamburg (hereafter: *Dictata*) – provides a correct quantification, consistent with the exposition given by Huygens in his *The Pendulum Clock* (1673), so that it can be dated to during or after the same year.[69] Neither of the commentaries alters the essence of

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De Volder, *Experimenta*, 130^r-130^v. The use of Latin and the fact that such a Latin text is underlined in the manuscript (rendered in italics in the transcription) indicates that it was taken *viva voce* from De Volder, i.e., it was a dictated part of the notebook. None of these Latin sentences can be found verbatim in the disputations. The first sentence, however, is derived from Archimedes’ postulate, whose discussion dominates disputation 2 (held on 15 May 1677: usually, the text of disputations was printed beforehand: Wiesenfeldt, “Academic Writings”). In turn, the first part of the second sentence amounts to what De Volder maintained in thesis 2 of disputation 1 (held on 14 October 1676), while the second part, (“[…] *falsum est*, *elementa in suis locis non esse gravia*”) is notably absent from the printed text. It might be that De Volder himself reported, during the lecture, that he had printed such a thesis, as entailed by his idea that air is heavy, or, alternatively, that he meant to have had printed only the first part of the sentence: in any case, he did overtly relate his (unprinted) claim to his printed text. Experiment 24 was aimed at demonstrating that mercury presses on water like air does. It was a variation of Torricelli’s experiment, and performed by inserting a tube filled with mercury in a basin filled with water, after which the mercury descends in the water until its level in the tube reaches a condition of equilibrium with the weight of a volume of water equal to that of the portion of the tube immersed in water.

[67] See Collacciani’s chapter in this volume.

[68] Hamburg, Staats- und Universitätsbibliothek Hamburg Carl von Ossietzky, Cod. Philos. 273, 156. The copy extant at The Hague (Koninklijke Bibliotheek, Ms. 72 A 7) contains also parts of the other commentary.

[69] Hamburg, Staats- und Universitätsbibliothek Hamburg Carl von Ossietzky, Cod. Philos. 274, 66. Other copies are extant at the Leiden University Library (Ms. BPL 2841, fols. 1^r-32^r), at the British Library (Ms. Sloane 1216, fols. 75-128), at the Biblioteka Narodowa (Warsaw; Ms. BN Rps 3365 II), and at the National Library of South Africa (Pretoria;

Descartes's explanation of the lack of the sensation of pressure under water as given in *Principles* IV.26, which is integrated in the *Dictata* with the account given in the aforementioned letter to Mersenne.[70] The text of De Volder's *Notulae* is particularly interesting as it expressly addresses Stevin and Boyle's solution:

> here it is possible to give reason of that issue, about which it is debated so vehemently, namely, why divers do not feel, in water, its weight. Stevin imagines a certain container, and in its bottom a man parallel to the horizon: what happens [when] water is poured in the container? He does not feel water at all. But if there is a hole in the bottom, by which the water can descend, and if [a man] covers it with [his] body, he then eventually feels the water completely. He [Stevin] (and Boyle follows him) believes that water actually presses, but because it presses uniformly, one does not feel it. Which if it were plausible, it will be plausible also this, namely that [someone] completely squeezed by a press does not feel pressure. In fact, if a body is solid, it does not feel pressure, or in the case that all the parts in man are full of water. However, since the [human] body is hollow, not filled with water but by air, it feels [the pressure] completely. Therefore there must be another explanation, which, anyway, Boyle wanted to criticize. However, it is the most true, and even if Boyle testifies that he is not satisfied by our author, he, however, does

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MSD27). The manuscript BN Rps 3365 II includes also a commentary on Descartes's *Meditations*. The manuscripts of De Volder's commentaries extant at Hamburg come from the private library of Zacharias Conrad von Uffenbach (1683-1734).

[70] "[…] deduci potest istius vulgaris experimenti in quo enodando plurimi frustra insudarunt, cur nimirum fiat, quod urinatores aliisque homines sub aqua degentes nullum sentiant aquam supra incumbentis pondus: huius enim ratio ex iis, quae hoc paragrapho adferuntur, manifesta est. Etenim si homo constitutus in puncto ex. gr. 3, premeretur aqua 3, 4 deorsum ut occuparet locum 2, necessario aqua, quae in 2 est, eadem mole 1 est corpus hominis ascenderet versus 3, quae cum aequali impetu huic ascensui resistat, efficit etiam, ut homo in 2 nullo pacto deorsum premi queat, unde nec mirum est, eum nullum supra se sentire pondus, quippe cuius tota vis in ea consistit pressione," De Volder, *Dictata*, 100.

> not propose anything which challenges [it] in any way.[71]

De Volder thus reverts to Descartes's solution, which is further explained by reducing it to an abstract, static model: De Volder claims that we do not feel pressure in water, in the same way as when we 'sustain' a weight on a balance on which equal weights are appended, we do not feel any pressure from it. Indeed, in both cases equal weights sustain themselves.[72] The same reductionist approach is to be found in his commentary on Descartes's explanation of the behaviour of a body in equilibrium with a fluid (*Principles* II.56-57), in which it is surrounded by particles pressing in all directions (see Figure 6), and forming infinite circles around it. According to De Volder's reading (in his *Notulae*), one can avoid the difficulties entailed by hypothesizing infinite circles of matter in motion – which amounts to state that the fluid is not in equilibrium, as the slightest bigger force exerted by one particle can re-direct the movement of all the other particles, like when a small weight is added to a balance – just by considering the pure equilibrium of forces in a medium.[73]

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[71] See the next note.

[72] "[…] posse hic rationem dari rei, de qua tam acriter disputatur, id est: cur urinatores non sentiant infra aquam eius gravitatem. Stevinus fingit vas quodpiam, et in eius fundo hominem horizonti parallelum, vasique aquam infundit, quod fit? Non sentit omnino aquam. Si vero in fundo sit orificium, per quod aqua descendere potest, idque si corpore tegat, omnino tunc demum sentiet aquam. Is, eumque secutus Boyle, putat aquam premere quidem: sed quia undique premit aequaliter, non sentire. Quod si verosimile sit, etiam et id verosimile erit, quod scilicet omnino a torculari pressus non sentiet pressionem. Verum quidem enim si corpus solidum esset, non sensurum pressionem, aut si omnia in homine essent aqua repleta. Cum vero cavum sit corpus, non aqua sed aere repletum, omnino sentiet. Alia ergo causa esse debet, quam licet Boyle voluerit impugnare. Verissima tamen est, et quamvis Boyle testatur sibi ab autore nostro non esse satisfacturum, nil tamen, quod aliquo modo urget, profert. Concipiamus itaque hominem in aquis mediis constitutum, non sentiet (si premeretur) aquam, nisi deorsum orientem, si vero ostendamus hanc pressionis vim, non ab omne sed alia aqua sustineri, causa certa est, concipiamus ergo cylindrum, aquam ipsi incumbentem, si hic descenderet, alius ipsi aequalis ascendere deberet, cum vero sint aequilibrio, non potest unus descendere, nec premere. Si vero concipiamus aperturam quam tegit omnino, sentiet pressionem quia tunc una aqua descendere potest non ascendente alia, sed aere, ut si duo habeamus bilances, et utrisque imponamus 100 ll, si quis manui sustineat alterutram, non sentient pressionem, quia ab altera parte est aequalis." De Volder, *Notulae*, 235-236.

[73] "[…] dico demonstrationem nostram non uti talibus circulis, sed fluidi aequilibrio, quod si non facere, pars quae

6. Conclusion

As a conclusion, is worth reminding ourselves that for De Volder the explanation of the phenomena of cohesion of bodies in open air – like the Magdeburg hemispheres – and that of floatation (including the hydrostatic paradox) are based on the same rationale, namely Archimedes' model. So that, according to De Volder's *Experimenta*, both in the case of the hemispheres that sustain a weight dependent only on their diameter, and not on their volume (experiment 3), and in that of the hydrostatic equilibrium of the water contained in an asymmetrical, U-shaped container (experiment 25), shows that fluids press only by lines perpendicular to the horizon, upwards and downwards, and not by lateral or oblique lines. Of course, it is possible to make De Volder's statement acceptable by interpreting it as meaning that the pressure of fluids depends only on their height: so that it can be transmitted along oblique lines, but it increases or decreases only according to vertical lines. Experiment 3, at most, can prove that what matters in the cohesion of hemispheres is the pressure exerted perpendicularly with respect to their line of cohesion viz. their diameter, though this is not what De Volder states; moreover, it could prove that pressure depends only on the height of a fluid only if it were performed at different heights: but, again, this was not done by De Volder in the course of this experiment.

Ultimately, De Volder did not account for the phenomenon of the lateral pressure of fluids: a phenomenon which he could not ignore, it having been described and accounted for by Stevin himself, from whom De Volder borrowed, in his *Experimenta*, the explanation

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praevaleret, tolleret motum particularum, in contrarias partes motarum, unde haec aucta viribus reliquas secum aget, versus easdem partes, atque adeo non stagnans amplius, sed motum erit fluidum […], si enim tot sunt particulae, quae impellunt versus orientem ac versus occidentem, necessario manebit eodem in loco. Si vero plures ab oriente, movebitur versus occidentem: quod in stagnante esse nequit. Res haec commodius explicari nequit quam exemplo bilancis […].” De Volder, *Notulae*, 117-118.

for the lack of the sensation of pressure under water.[74] Notably, according the inventory prepared by him in 1705, when he left his academic post, the Leiden *theatrum* was provided with a “glass with an opening in the middle to demonstrate the lateral pressure of the air,”[75] an instrument, however, most probably used after 1676-1678. Still, his strict reliance on an Archimedean model of floatation, in which only upwards and downwards pressures are taken into account, and his reductionist approach to the model of the lever both in hydrostatics and in pneumatics did not allow him to account for lateral pressure in 1670s. In other words, De Volder conceived the equilibrium of liquids as that of solids put on a scale (in which forces are exerted upwards and downwards). De Volder failed to capture a conceptual shift well described by Chalmers, namely the passage in the conceptualization of pressure, begun with Stevin and concluded with Newton. This passage went from the ‘common’ interpretation of pressure, understood as pressing or weighing – in principle, not differentiated from weight itself – to pressure understood in a ‘technical’ sense:

> a key difference between pressure in the common sense and pressure in the technical sense is that the former relates to forces on bounding surfaces between media whereas the latter refers to forces within the body of media. Another is that, from the technical point of view, pressure is a scalar not a vector. Directed forces, such as those that occur at the boundary of a liquid are determined by variations of pressure, the gradient of pressure in technical terms, rather than by pressure itself. The technical concept of pressure in fluids breaks from the directedness implicit in the verb ‘to press’ from which ‘pressure’ originally derived and which is presupposed in the concept of

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[74] Stevin, *Hypomnemata mathematica*, 146-147.

[75] “Een glas met een openingh in het midden ad demonstrandam aëris pressionem lateralem,” Molhuysen, *Bronnen*, vol. 4, 104*.

> pressure in its common sense.[76]

As seen above, fluids, according to De Volder's printed texts, and following Descartes, do not ultimately press on themselves. In the *Experimenta*, following Boyle, De Volder argued for their internal pressure. Even in his interpretation of Descartes's *Principles* II.56-57, De Volder does not take into account the pressure exerted by the particles of fluids on each other.

De Volder's appropriation of Stevin's and Boyle's ideas – which informed his experimental teaching – was ultimately inconsistent with his strict reliance on an Archimedean model and with his Cartesianism, which did not provide him with the conceptual means to describe the behaviour of fluids. From 1698 onwards, Rohault's *Treatise on Physics*, which shows a reliance on Boyle's solution to the issue of the lack of the sensation of pressure under water, was apparently adopted as a textbook by De Volder but did not help him in overcoming his difficulties – although we have no direct insights on his use of Rohault's text.[77] Other factors, certainly, were behind his late dissatisfaction with Descartes's ideas: in particular, with his idea of material substance, which not allowing for any argument for its activity made it necessary to revert to an external mover, as discussed in his correspondence with Leibniz. It was difficulties such as these, combined also with his early teaching of Boyle's experiments at Leiden, that led ultimately to a divergence between his experimental and theoretical physics.

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Figure captions

FIGURE 1 Cohering marbles used by De Volder. Source: De Volder, *Experimenta*, 78v. Courtesy British Library, Ms. Sloane 1292.

FIGURE 2 Cohering marbles sold by Johannes Joosten van Musschenbroek. Source: Van Musschenbroek, *Descriptio antliae*, plate 3, figure 2. Utrecht University Library, call number: U-MUS: C 20 MUS 3#OUD, <http://dspace.library.uu.nl/handle/1874/356862>, accessed 5 February 2019. Public domain.

FIGURE 3 Magdeburg hemispheres sustaining weights. Source: Von Guericke, *Experimenta nova*, 106. ETH-Bibliothek Zürich, signature: Rar 5021, <https://www.e-rara.ch/doi/10.3931/e-rara-9099>, accessed 5 February 2019. Public domain mark 1.0.

FIGURE 4 An inverted asymmetrical syphon used to demonstrate that the pressure of water depends only on its height. Source: De Volder, *Experimenta*, 133r. Courtesy British Library, Ms. Sloane 1292.

FIGURE 5 Instrument aimed at demonstrating the hydrostatic paradox (De Volder's cylinder). Source: Lufneu, "Memoire communiqué," 385. Yale University Library, LSF-Beinecke, call number: WA 10332. Public domain.

FIGURE 6 Idealized representation of the transmission of pressure in water according to Descartes. Source: Descartes, *Principia philosophiae*, 63. Library of Congress, call number: LC B1860 1644, <http://hdl.loc.gov/loc.rbc/Rosenwald.1431.1>, accessed 5 February 2019. Public domain.

Figure 1

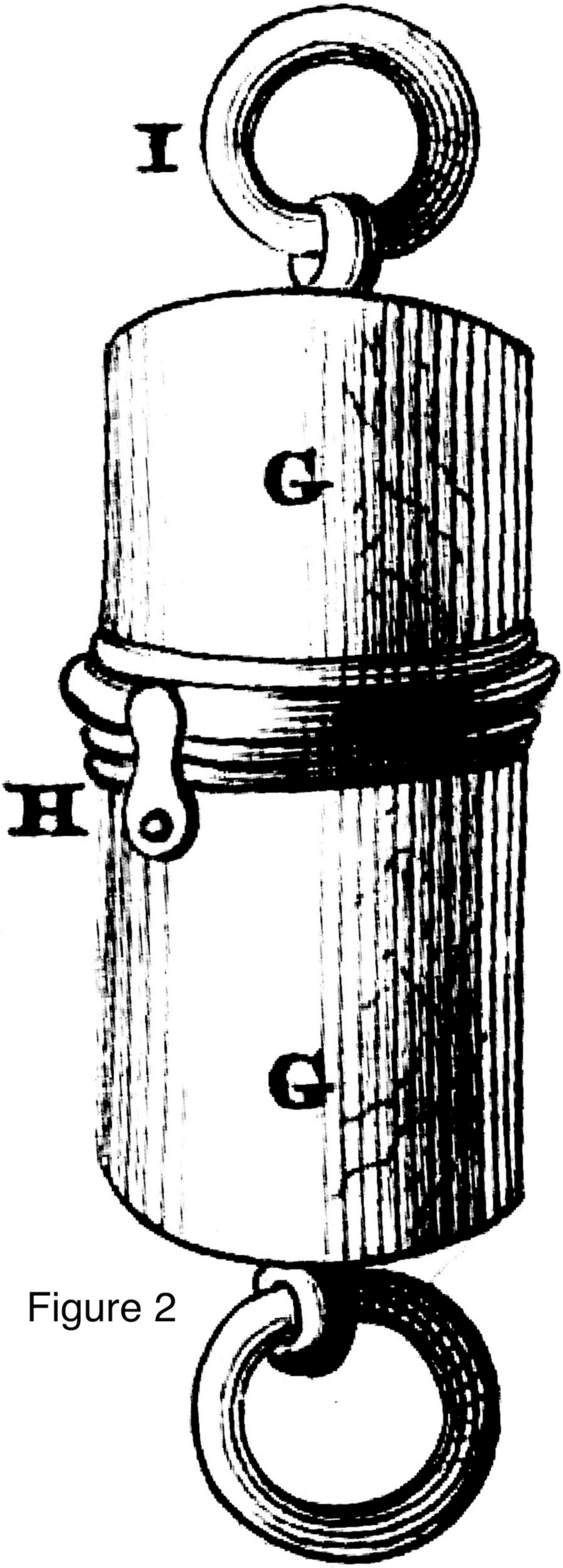
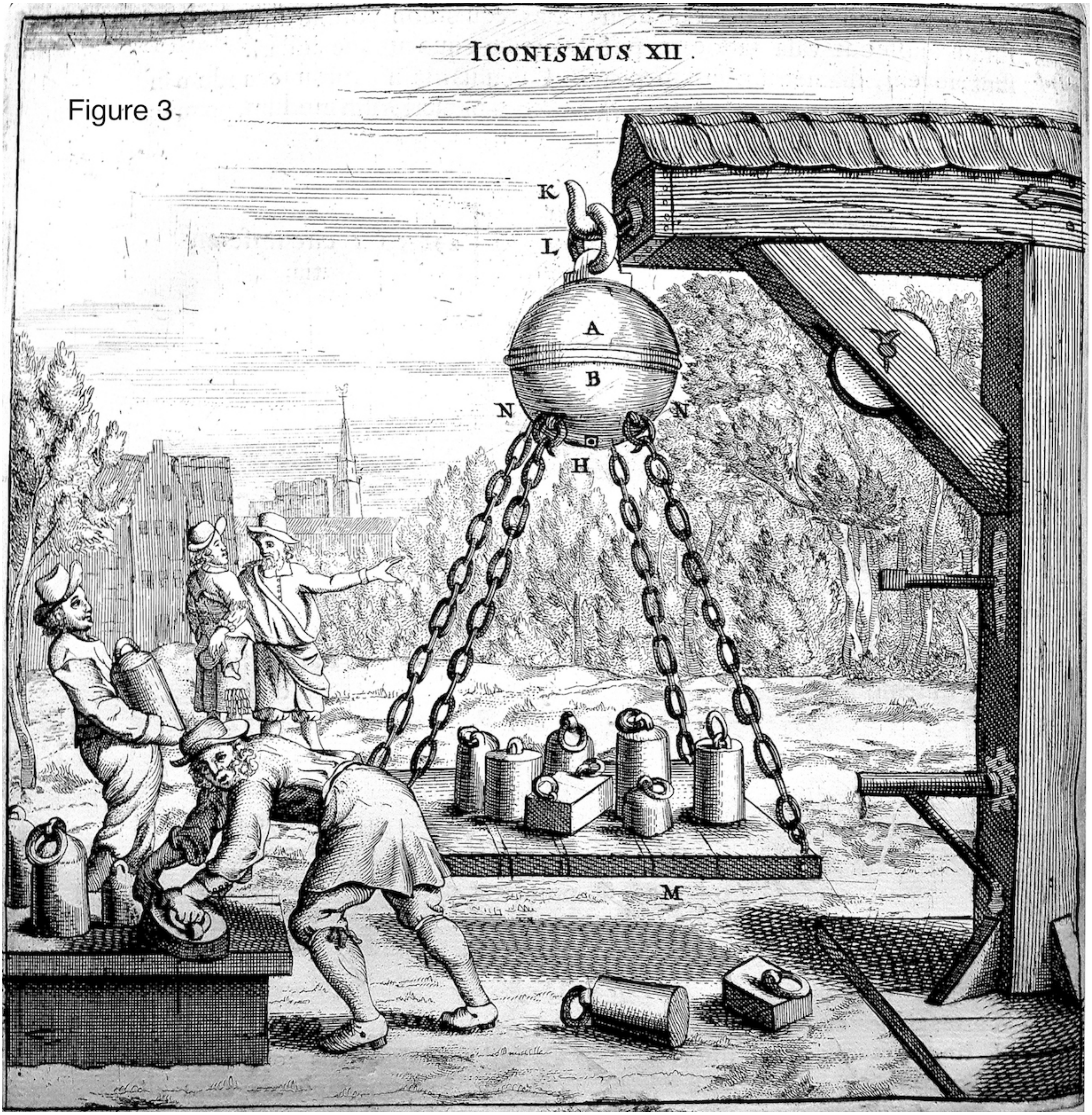


Figure 2

Figure 3



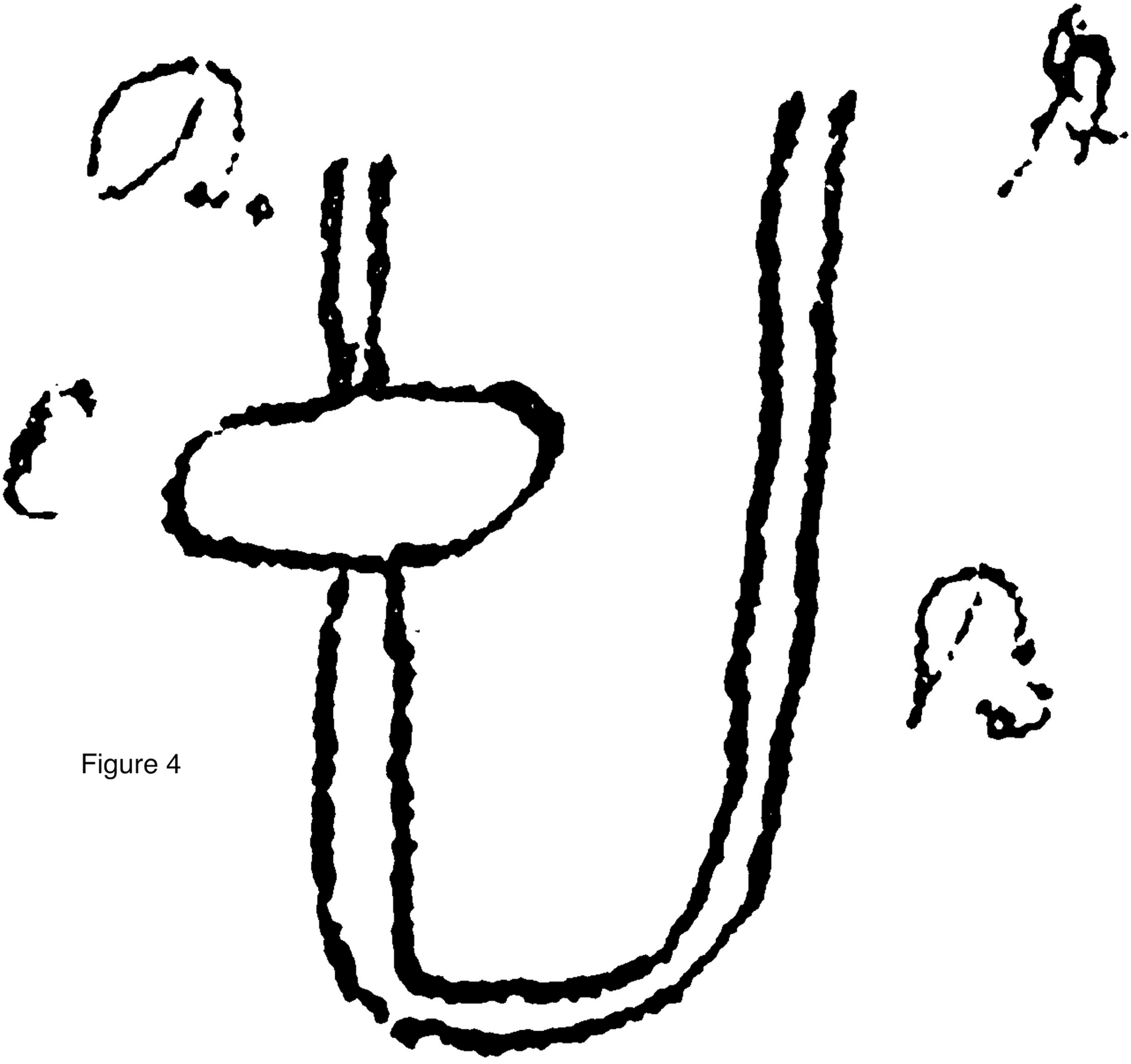


Figure 4

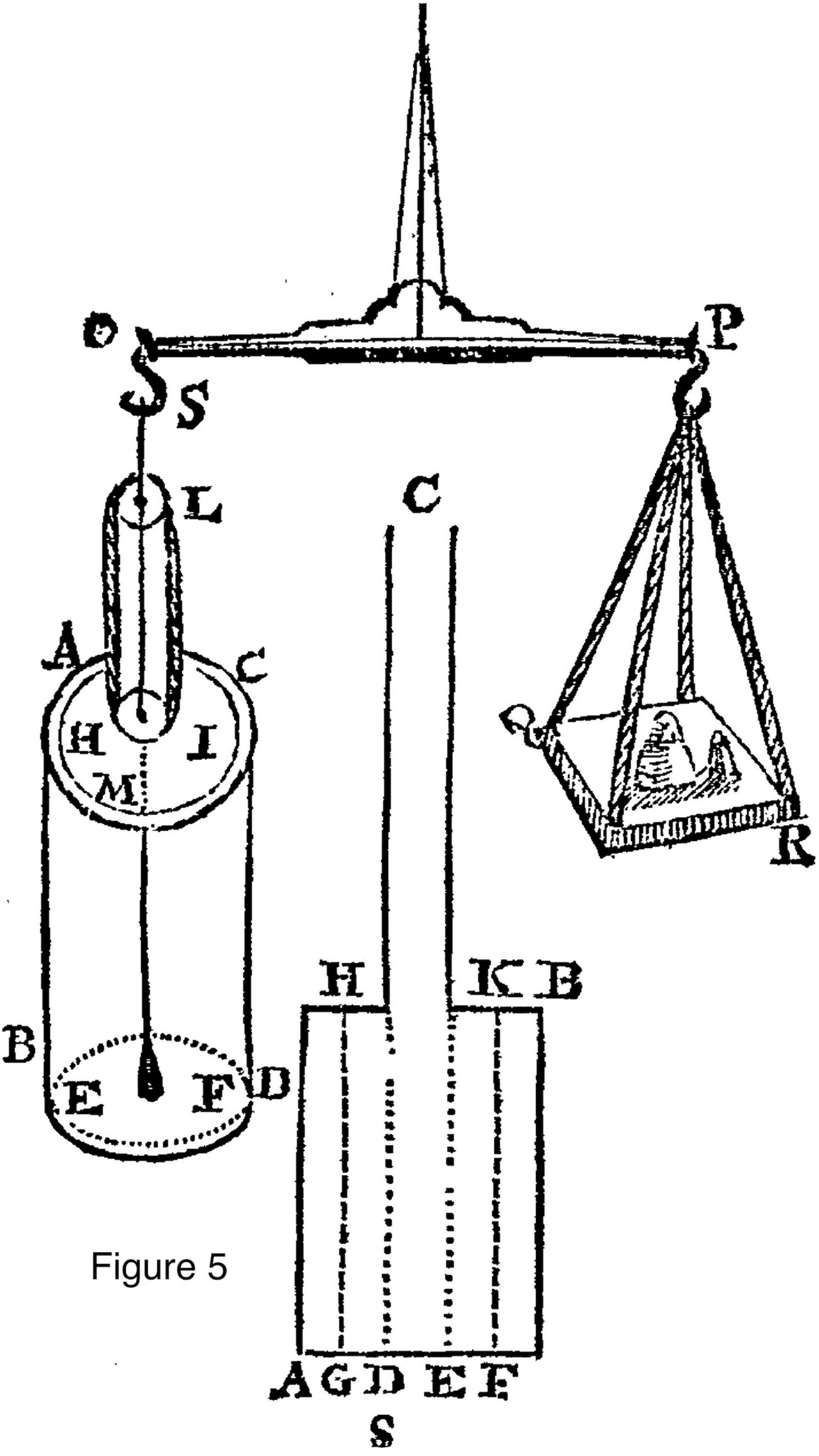


Figure 5

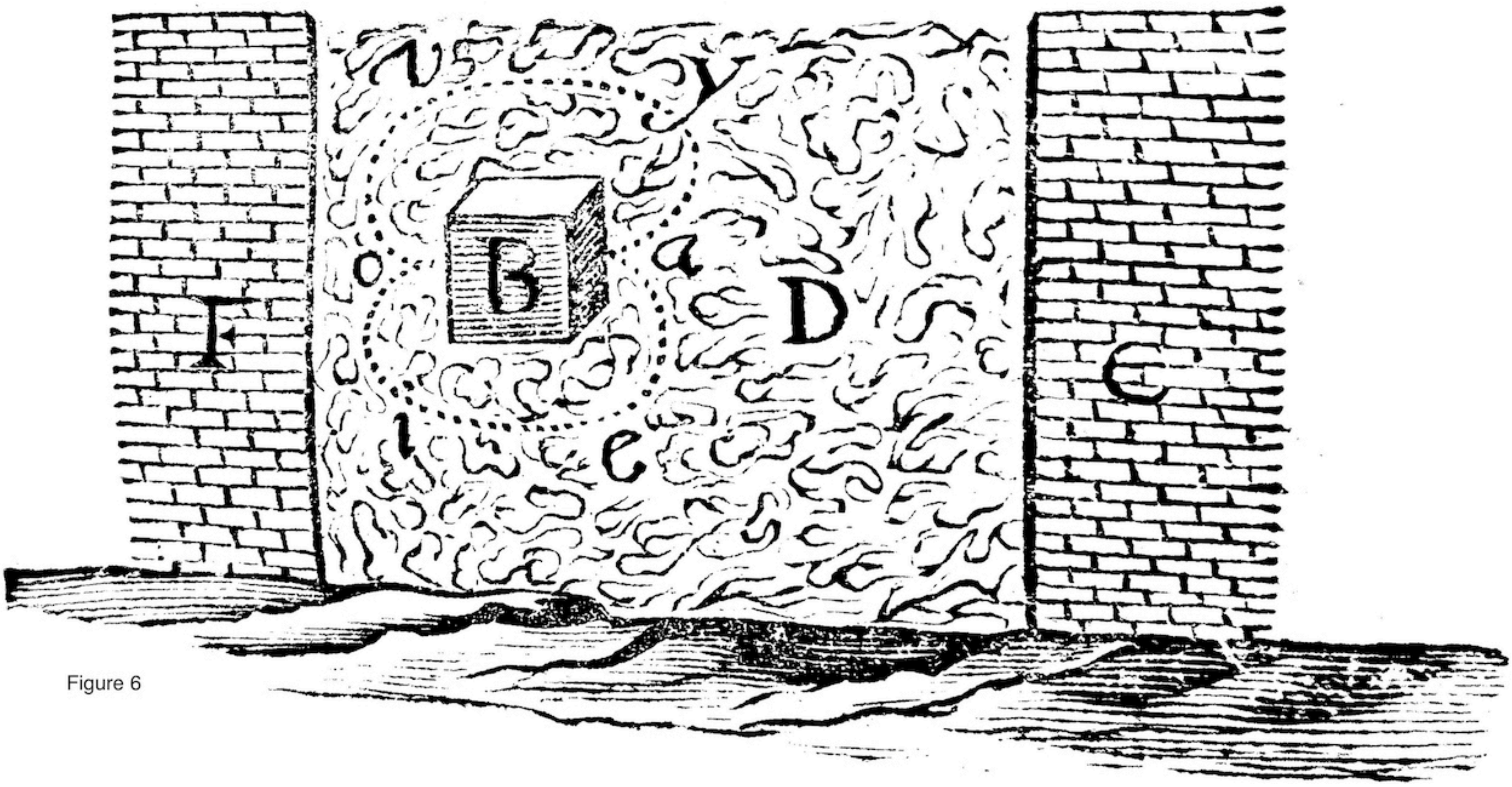


Figure 6