EXPORTING SCIENTIFIC INSTRUMENTS AROUND 1700

The Musschenbroek Documents in Marburg

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1. Introduction

The Musschenbroek workshop in Leiden, active from the 1660's to 1748, was one of the finest scientific instrument-making workshops in history. Its products found their way to patrons both in and outside the Netherlands, and some one hundred of them survive in museums and university collections. The largest number is held in the Museum Boerhaave as part of the collection of physical instruments of Leiden University, the Leiden Cabinet of Physics.

The workshop was discussed in some publications by Crommelin, founder and first director of what is now the Museum Boerhaave.[1] The most detailed information on the workshop in print are the entries in an alphabetical list of Dutch instrument makers,[2] published in 1950 by Rooseboom, who succeeded Crommelin as director of the museum. In his classic book on scientific instruments, Daumas based his description of the Musschenbroek workshop and its products on these publications of his Leiden colleagues.[3] Since then nothing substantially new has appeared on the subject.

Drawing on a variety of sources which Crommelin and Rooseboom have either not fully exploited or not seen at all, I am now preparing a book on the

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* I wish to thank my colleagues at the Museum Boerhaave, and my supervisors, prof.dr. H. Floris Cohen and prof.dr. P.W. Klein, for reading and commenting on earlier versions of this paper.

[1] To mention only the first in English: "Physics and the art of instrument making at Leyden in the 17th and 18th centuries", in *Lectures on Physics and Physiology. American Week. Leiden 5-10 July 1926* (Leiden: Sythoff, 1926). The gist of it was incorporated into C.A. Crommelin, *Descriptive catalogue of the physical instruments of the 18th century (including the collection 's Gravesande-Musschenbroek) in the Rijksmuseum voor de Geschiedenis der Natuurwetenschappen (National Museum of the History of Science) at Leyden* (Leiden: Communication of the museum no. 81, 1951).

[2] Maria Rooseboom, *Bijdrage tot de geschiedenis der instrumentmakerskunst in de Noordelijke Nederlanden tot omstreeks 1840* (Leiden: Mededeling no. 74 uit het Rijksmuseum voor de Geschiedenis der Natuurwetenschappen, 1950), pp. 14-16 and 102-109.

[3] Maurice Daumas, *Les instruments scientifiques aux XVIIe et XVIIIe siècles* (Paris: Presses Universitaires de Paris, 1953). In the English translation, *Scientific instruments of the seventeenth and eighteenth centuries and their makers* (London: B.T. Batsford, 1972) the pages are 84-87, 138-140 and 247-248.

Musschenbroek workshop. The best material is found in the archives of its patrons, and this paper gives a detailed analysis of a particularly rich and rewarding group of such documents. They are related to the acquisition of some sixty physical, optical, anatomical and medical instruments by professor Johann Daniel Dorstenius (1643-1706) in Marburg, Germany.[4] These documents, which were never published and have been discussed only superficially,[5] are of interest for several reasons.

To begin with, they are a rarity in themselves. Instrument makers have of course always communicated with their patrons, but as a rule this will have meant having a conversation in the workshop. At best, such contacts have left indirect traces in, for example, travel diaries. When personal contacts were impossible, the obvious alternative – at least for literate makers[6] – was an exchange of letters with patrons. Yet, few such correspondences seem to have been located. The only published example I know are Fahrenheit's letters to Leibniz (1715-1716) and Boerhaave (1718-1729) and Brander's letters (1766-1775) to the director of the astronomical observatory at Kremsmünster monastery in Austria.[7]

Of course, source materials do not deserve close analysis because of their rarity, but because of their content. There are indeed three major reasons why the Musschenbroek documents in Marburg are of interest for the history of science and the scientific instrument industry.

First, Dorstenius, whose career is discussed in section 4, was one of the

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[4] Hessisches Staatsarchiv, Marburg, file 305a A IV 4a, Nr. 6. In April 1987, I obtained a microfilm of these documents (73 frames); in November 1989 I have seen the documents themselves. I am grateful to Dipl.-Archivar Klingelhöfer for his help in making the documents accessible and for answering further queries which presented themselves during the writing of the present article.

[5] Dieter Hof, *Die Entwicklung der Naturwissenschaften an der Universität Marburg/Lahn zur Zeit des Cartesianismusstreites bis 1750* (Ph.D. diss. Marburg/Lahn, 1971), pp. 48-50 and 136-139. His - not always accurate - discussion of the documents was copied in Rudolf Schmitz, "Die physikalische Gerätesammlung der Universität Marburg im 17. und 18. Jahrhundert," *Sudhoffs Archiv* 60, 1976, pp. 375-403, esp. 375-377.

[6] See the revealing postscript to a letter written in 1705 by the London optician John Yarwell regarding some telescope lenses ordered from him by a Yorkshire patron: "This is the longest letter I ever writ concerning my bisness, and I hope I shall never wright one soe long agane in all my life to come, which if it had not been to you I should never have writ, for very littel doe I love it." Quoted from Anthony Turner, *Early scientific instruments* (London: Sotheby's Publications, 1987), p. 209.

[7] P. van der Star, ed. *Fahrenheit's letters to Leibniz and Boerhaave* (Leiden/Amsterdam: Rodopi, 1983), and Ansgar Rabenalt, ed., "Briefe Georg Friedrich Branders, mechanici in Augsburg, an Placidus Fixlmillner OSB, 1. Direktor der Sternwarte von Kremsmünster," in *Studien und Mitteilungen zur Geschichte Benediktiner-Ordens und seiner Zweige*, herausgegeben von der Bayerischen Benediktinerakademie, Jg. 1985, Band 96, Heft I/II (EOS Verlag Erzabtei St. Ottilien, 1985), p. 145-195.

earliest university professors to participate in the exciting novelty of experimental science. The Marburg documents allow a detailed account to be given of how he provided himself with the necessary tools and knowledge. It must be remembered that public lectures on natural philosophy with special apparatus really only became common in the eighteenth century. Until 1700, the practice of experimenting had mainly been restricted to the well-known scientific societies in Florence, London and Paris, and had found a foothold in only a few universities, of which Leiden had been the first. No systematic courses of experimental physics had yet been published when Dorstenius acquired his instruments; Desaguliers and 's Gravesande were still children, Nollet was not even born. Dorstenius probably did well to patronize such a well-informed instrument maker as Johan van Musschenbroek. From his close contacts with Leiden University, Musschenbroek could play an active role in the dissemination of science, which went well beyond the simple delivery of material goods. In fact, his letters often read more like those of a teacher than of a business man.

Secondly, the Marburg documents provide new information on the repertoire of the Musschenbroek workshop in its early years. Until now, we were far better informed on the last decades of the workshop, when the cooperation (1717-1742) with professor 's Gravesande led to the construction and marketing of dozens of new philosophical instruments. Yet, an analysis[8] of the growth of the physical cabinet at Leiden University – traditionally one of the Musschenbroeks' major patrons – suggested that by 1700 the workshop's repertoire already extended well beyond the air-pumps and microscopes which survive and with which, consequently, the workshop's early period is usually associated. This is certainly confirmed by the Marburg documents, which contain a wealth of information on the appearance and the prices of Musschenbroek's early products. For the benefit of historians of scientific instruments, this information will be given and discussed in considerable detail in section 6.

Thirdly, the Marburg documents are unique for the information they contain on the business organization of an early scientific instrument-making workshop. Johan van Musschenbroek emerges as an innovative entrepreneur who, as discussed in section 5, may well have been the first instrument maker to offer his products at a fixed price instead of negotiating the price with each individual customer. They also shed light on that notorious problem in the study of the scientific instrument industry of establishing the precise contribution of an instrument maker to the goods he offers. What did he construct himself? To what extent did he assemble parts made by other specialists? How much was simply a matter of selling ready-made products? "By 1700," writes G.L'E.

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[8] Peter de Clercq, *The Leiden Cabinet of Physics* (Leiden: Communication 233 of the Museum Boerhaave, 1987), esp. p. 5.

Turner, "the London instrument-making trade was a complex interlocking of specialist makers and retailers," which is hard to disentangle "because written accounts of the structure of the trade by tradesmen seem to be non-existent."[9] To this the Marburg documents are a welcome exception, and section 8 presents what rare glimpses they offer us of these elusive business aspects of an instrument-making workshop around 1700.

2. The Musschenbroek workshop in Leiden

As immigrants from the Southern Netherlands, the Musschenbroeks had settled in Leiden around 1600 and established themselves as brass-founders. For two generations, they were well known for their excellent oil lamps. After the workshop had branched off onto scientific instruments, its original specialty was echoed in the name of the family house and workshop: 'De Oosterse Lamp' ('The Oriental Lamp'). It was used as a trade-mark – often combined with the crossed keys from the Leiden coat-of-arms – on many a Musschenbroek instrument.

The first instrument maker in the family was Samuel Joosten van Musschenbroek (1639-1681). From the early 1660's onward, his patrons included the anatomists Frederik Ruysch and Reinier de Graaf and the microscopist Jan Swammerdam. In the 1670's, Samuel constructed air-pumps for the Leiden professors of philosophy, Burchardus de Volder and Wolferdus Senguerdius.

He was succeeded by his brother Johan Joosten van Musschenbroek (1660-1707), the author of the documents discussed in this article. Having been trained in the art by his brother and having inherited his utensils, Johan ran the workshop for a quarter of a century. In 1694 he acquired a house along the fashionable Rapenburg canal, where the workshop was to remain until its dissolution some fifty years later. Within a hundred yards lay the main institutions of Leiden University, with which the Musschenbroeks' careers were intimately connected. A former church to his left housed the university library and the *Theatrum Anatomicum*. Over the bridge lay the university building, the centre for academic ceremonies to this very day. On its roof an astronomical observatory had been erected; behind it stretched the botanical garden. And in an alley next to the university building lay the *Theatrum Physicum*, founded in 1675 – a first in Europe – to allow professor De Volder to show by experiment "the truth and

[9] G.L'E. Turner, "Micrographia historica: the study of the history of the microscope," *Proceedings of the Royal Microscopical Society* 7, 1972, pp. 120-149. Quoted from the reprint in G.L'E. Turner, *Essays on the history of the microscope* (Oxford: Senecio Publishing Company, 1980), pp. 9 and 11.

certainty of the postulates and theories presented to the students in Physica theoretica." Leiden, in the words of a late eighteenth-century professor at that university, was "the cradle and nursery of experimental physics."[10]

It was almost within the university then that Johan Joosten van Musschenbroek lived and worked and saw his two sons grow up. Petrus (1692-1761) was to choose an academic career, teaching natural philosophy at the universities of Duisburg, Utrecht and Leiden and writing text-books on the subject. His elder brother Jan (1687-1748) followed in his uncle's and father's footsteps and brought the family workshop its greatest fame. His cooperation with Newton's 'apostle' on the continent, Willem Jacob 's Gravesande, is a well-known chapter in the history of science. With Jan van Musschenbroek's death, the family tradition of instrument making came to an end.

3. Musschenbroek's German contacts

To place the Musschenbroek documents in Marburg in perspective, it should be noted that Dorstenius was by no means the only German to patronize the Leiden workshop. If we may believe the Leipzig instrument maker Jacob Leupold, Germany around 1700 imported most of its scientific instruments, and one of the suppliers was Holland.[11] Among the Musschenbroeks' patrons were the landgraves of Hesse-Kassel; the Astronomisch-Physikalische Kabinett in Kassel still preserves some of their instruments, including the earliest known diagonal Musschenbroek air-pump, dated 1686.

There are also contemporary publications which testify to the great esteem in which the Musschenbroek workshop was held in early eighteenth-century Germany. In 1707 Christian Heinrich Erndtl visited "Mr. Muschenbroek's, who is the most famous Mechanik of his Time" and carefully listed the instruments he

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[10] For early physics at Leiden University see E.G. Ruestow, *Physics at 17th and 18th century Leiden. Philosophy and the new science in the university* (The Hague: M. Nijhoff, 1973); C. de Pater, "Experimental physics," in *Leiden University in the seventeenth century. An exchange of learning*, ed. Th.H. Lunsingh Scheurleer and G.H.M. Postumus Meyes (Leiden: UP Leiden/ E.J. Brill, 1975), pp. 309-327. The quotations are found in De Clercq (n. 8), *The Leiden Cabinet of Physics*, pp. 4 and 5.

[11] In a petition to the Elector of Saxony in 1717, Leupold pointed out that "die Mechanischen Wissenschaften bisherr ... in ganz Deutschland dergestalt in slechtem Zustand sich befanden, dass man die meisten Instrumenta theils aus Frankreich, theils aus Holl- und Engeland mit schweren Kosten und Ausführung des Geldes aus dem Lande bringen müssen ..." Quoted from Karl Werner, "Aus der Frühzeit physikalischer Werkstätten - kleiner Beitrag zu einem Lebensbild Jacob Leupolds (1674-1727)," *Zeitschrift für Geschichte der Naturwissenschaften, Technik und Medizin* 3, 1962, pp. 45-56, esp. p. 46.

saw with their prices.[12] Five years later the workshop was visited by Zacharias Conrad von Uffenbach. In his travel diary he comments on its products, following a printed trade catalogue. In passing we learn of two German customers of the workshop: Friedrich Hoffmann in Halle had bought a Papin's digester (which had exploded in his face), while Uffenbach himself had one of its magic lanterns and several of its microscopes.[13]

Valentini's 'Rüst- und Zeughaus der Natur'

The most important contemporary German publication for our purpose is a remarkable survey, published in 1714 under the title (in my translation) *New arsenal of nature, showing the wonderful, curious and very useful machines and instruments which the present-day physicists make use of to explore natural causes*.[14] This book has not received any attention from historians of scientific instruments and requires an introduction. Its compiler, Michael Bernhard von Valentini (1657-1729), started as a medical practitioner in his hometown Giessen in the county of Hesse-Darmstadt. In 1686 he travelled to Leiden, London and Paris to meet the leading scientists and physicians of his time. Back in Giessen, he became professor of medicine at the university.[15] Valentini himself owned several instruments by Musschenbroek.[16] His book is full of references to Musschenbroek, whom he ranks among the famous instrument makers in Germany and the Netherlands ("die berühmte Mechanici in Hoch- und Nieder-Teutschland"), and contains many engravings of Musschenbroek instruments.

An appendix to Valentini's survey lists the repertoire of three instrument

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[12] *The Relation of a Journey into England and Holland in the Years 1706 and 1707 by a Saxon Physician ... By CH.ED.* [= Christian Heinrich Erndtl] *Physician in Ordinary to the King of Poland, Elector of Saxony, &C.* (London: Printed and Sold John Morphew, near Stationers-Hall, 1711), pp. 61-63. Translated from the Latin *De itinere suo angelico et batavo, annis 1706 et 1707 facto, relatio ad amicum* (Amsterdam: apud Janssonio Waesbergios, 1711).

[13] Z.C. von Uffenbach, *Merkwürdige Reisen durch Niedersachsen, Holland und England* (Ulm: Christian Ulrich Wagner, 1754), vol. 3, pp. 430-437.

[14] *Neu-auffgerichtetes Rüst- und Zeughaus der Natur. Worinnen die so wundersame/curiöse/auch sehr nützliche Machinen und Instrumenten/ deren sich die heutige Naturkündiger in Erforschung der natürlichen Ursachen bedienen/ su sehen und zu finden sind* (Franckfurt am Mayn: Verlegt von Johann David Zunners sel. Erben und Johann Adam Jungen, 1714). This survey contains 102 pages, several appendices and 40 large plates and appeared in vol. 3 of Valentini's *Museum museorum*, a compilation work mainly dealing with natural history.

[15] Ilza Veith, "Michael Bernhard von Valentini, non-specialist in medicine and science: physician of the Enlightenment," *Bulletin of the History of Medicine* 52, 1978, pp. 96-101.

[16] Vol. 3 of *Museum museorum* (see n. 14) contains *Anhang von verschiedenen Kunst- und Naturalien-Kammern, welche entweder rar zu bekommen oder gar nicht im Druck sind*. This appendix specifies the contents of 23 collections of curiosities of art and nature in various countries, including Valentini's own. Several of his *INSTRUMENTA, Physica, Mathematica, Anatomica, Chirurgica, Chymica* (pp. 104-105) are clearly from the Musschenbroek workshop.

makers. Two of these are Germans: Jacob Leupold and Christian Schober, both in Leipzig. The appendix opens with a *Verzeichnuss was obgemeldte und andere zur Physic, Anatomie, und Chirurgie dienende Instrumenten (wie sie zu Leyden in Holland von Jan von Muschenbroek gemacht werden) kosten*. As discussed hereafter in section 5, priced instrument-makers' trade catalogues of this early period are extremely rare. Yet, one must be careful. On inspection this is found to be not, as the title suggests, a trade catalogue issued by Jan van Musschenbroek at the time of publication of Valentini's book in 1714. Instead, it is as much a compilation as the book which precedes it and contains information dating back as much as twenty years. Many entries are evidently based on the letters and invoices which Jan's father Johan had written to Dorstenius between 1694 and 1703, and to which Valentini must have had access when he compiled his survey.[17] Some evidence of this will be presented in section 6.

4. Dorstenius at Marburg University[18]

The University of Marburg, a town situated on the river Lahn in the county of Hesse-Kassel in Germany, was founded in 1527 as the first Protestant university in the world. It was here that Johann Daniel Dorstenius (1643-1706) was taught and spent his academic career. Having taken his doctor's degree in the faculty of medicine in 1668, Dorstenius became professor of anatomy, surgery and botany in 1678. We get a glimpse of the hardships of a professor's life at an ill-equipped university when two years later Dorstenius asked for a rise in salary, claiming that "in the absence of a hortus medicus, [I have] for the benefit of the studying youth kept my own garden with a gardner at high costs, so that at my present low salary I am bound to die a wretched death."

When in 1689 the physics chair fell vacant, Dorstenius applied to the landgrave of Hesse-Kassel and was indeed granted the post *ad interim*. It is remarkable that Dorstenius, who had no previous experience in physics and had to start from scratch, was chosen in favour of another, eminently suited applicant. This was Denis Papin, who after the revocation of the Edict of Nantes had joined a number of his fellow Huguenots at Marburg University, where he was appointed

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[17] Valentini (n. 14), *Rüst- und Zeughaus* never explicitly mentions this correspondence. That Valentini used letters written to others than himself is, however, evident. Thus, he quotes a letter written to Dorstenius by the instrument maker Schober (p. 7), and gives a long quotation (in Dutch!) from a letter, dated Leyden 16 Nov. 1700, which Musschenbroek wrote "to a good friend" (p. 9).

[18] Unless otherwise stated this chapter is based on Hof (n. 5), *Die Entwicklung der Naturwissenschaften*. For the chronology of Dorstenius' career see also *Catalogus Professorum Academiae Marburgensis. Die Akademischen Lehrer der Philipps-Universität in Marburg von 1527 bis 1919*, bearbeitet von F. Gundlach (Marburg, 1927), p. 186.

professor of mathematics. Hof suggests[19] that he was not given the physics chair because the landgrave had better things for him in store. Indeed, in 1695 Papin was given a place in the court at Kassel. Yet one wonders why Papin should have been held in suspense for five years, during which he tried hard to find a better paid position elsewhere.[20] I therefore suggest another, pragmatic reason. At Protestant universities a professor of experimental physics was expected to furnish some if not all of his equipment, and men are known to have bought their way into a professorship by supplying the necessary apparatus.[21] With his garden, Dorstenius had shown that he was prepared to invest in his career. The university therefore had every reason to rely on his willingness to do the same for his new field of teaching.

Dorstenius' predecessor on the physics chair, the Cartesian Johann Jacob Waldschmiedt (1644-1689), had been the first in Marburg to allow practical observation into his teaching. It appears that at first Dorstenius did no more than just to follow in his predecessor's footsteps: there is no evidence that he offered experiments during the first years of his tenure. But this was to change after 1695 when, having held the post *ad interim* for five years, Dorstenius was made ordinary professor of physics in early 1695. The printed programme of his teachings for the academic year 1697 announces: "That [the experimental method] is the road I shall follow, and I shall thereby lift the veil of secret from many wonders so that we can admire God in Nature, and demonstrate things with the aid of costly machines, such as have not been seen in Germany before, and thus offer a complete private course of experiments."

That these 'costly machines' had not been provided by the university is evident from a letter which Dorstenius wrote to the landgrave in 1699. In this letter, he claimed that no decision had yet been taken regarding his salary since he was appointed ordinary profesor of physics four years ago. He asked to be allowed the yearly 60 German guilders which all his predecessors had received for this post, pointing out that he had bought the necessary instruments out of his own pocket. The landgrave fixed the rise of his salary at only 40 guilders.[22] I

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[19] Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, p. 53.

[20] On Papin see for example C.C. Gillespie, ed., *Dictionary of scientific biography*, vol. 10 (New York: Charles Scribner's Sons, 1974), pp. 292-293. In his application for the physics chair, written to the landgrave on 18 January 1690, Papin claimed that his cooperation with Huygens in Paris and Boyle in London made him a suitable candidate. The request was printed in E. Wintzer, *Denis Papin's Erlebnisse in Marburg 1688-1695. Mit Benützung neuer Quellen* (Marburg: N.G. Elwert'sche Verlagsbuchhandlung, 1898), p. 65.

[21] J.J. Heilbron, *Elements of Early Physics* (Berkeley: University of California Press, 1982), pp. 139-140.

[22] The episode is presented unclearly and inexactly in Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, p. 47. Dipl.-Archivar Klingelhöfer solved the matter by checking the original documents for me in the Hessisches Staatsarchiv (letter of 17 January 1991).

shall return to the implication of this in the conclusion to this paper.

5. A pioneer in marketing: the trade catalogue of 1694

Trade catalogues are a valuable source for the historian of the scientific instrument industry.[23] The very fact that an instrument maker issues a catalogue indicates a degree of professionalization. Instead of waiting for individual patrons to present their wishes and ideas, he actively offers what has apparently crystallized into a fairly rounded repertoire of products. The first instrument maker known to have taken this step is an Englishman, whose catalogue was published in 1701.[24] As a further sign of professionalization, instrument makers added fixed prices for their products, instead of negotiating a price with each individual customer. It has been claimed that the Musschenbroek workshop led the way with its printed catalogue of 1736.[25] In England this example is not known to have been followed before 1757, when the well-known 'retailer of the sciences' Benjamin Martin produced his first priced catalogue.[26]

In view of the above it is remarkable that the Musschenbroek documents in Marburg contain a hand-written trade catalogue, headed *Catalogue of all the instruments that are being made by me* (see the appendix for a full transcription). It is undated, but was announced in Musschenbroek's letter of 4 March 1694 and sent soon after that. From this document, the earliest known priced trade catalogue of any instrument maker, we can see that the Musschenbroek workshop began to play its pioneer role in marketing scientific instruments much earlier than it had been credited with.[27]

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[23] R.G.W. Anderson, J. Burnett and B. Gee, *A handlist of scientific instrument-makers' trade catalogues 1600-1914* (Edinburgh: National Museums of Scotland Information Series No. 8, 1990) gives the location of over 1500 printed trade catalogues. The year indication in the title is odd: the earliest catalogue mentioned is Prujean's of 1701 (see following note).

[24] *A catalogue of instruments/ made and sold by John Prujean, near New-College, in Oxford. With notes of the use of them*, printed at the end of R. Holland, *Globe notes* (Oxford, 1701).

[25] Anderson et al. (n. 23), *A handlist*, p. ii. This was the *Lyst der natuurkundige, wiskundige, anatomische, en chirurgische instrumenten welke by Jan van Musschenbroek te vinden zyn te Leyden*, inserted at the end of Petrus van Musschenbroek, *Beginselen der Natuurkunde, Beschreven ten dienste der Landgenooten* (Leiden: Samuel Luchtmans, 1736).

[26] Anderson et al. (n. 23), *A handlist*, p.ii, referring to John R. Millburn, *Retailer of the sciences. Benjamin Martin's scientific instrument catalogues, 1756-1782* (London: Vade-Mecum Press, 1986).

[27] This is corroborated by further priced trade catalogues of the Musschenbroek workshop dated before 1736, which I located and intend to incorporate into my announced book. Meanwhile, it may be useful to researchers to have the list in telegraphese: (1) 1694; (2) 1707 (transcribed in Erndtl, see n. 12); (3) 1711 (quoted in parts in von Uffenbach, see n. 13); (4) 1714 (compiled by Valentini, see n. 14); (5) c. 1710-1720, manuscript, Dutch, with prices, in the Museum Boerhaave, Leiden; (6) c. 1730-1735, printed, Latin, with prices, in the Deutsches Museum, Munich.

Turning now to the content of this document, we see that two thirds of the entries in the catalogue are instruments for research and teaching. The last third (nrs. 18-27) are medical appliances. The postscriptum states that these were his best sellers: "trusses and harnesses for those with humps is my principal line of trade," and continues "I make an infinite number of other items in daily use," which seems to refer to wares such as could be supplied by any brass-founder or mechanic.

Knowing how prominently philosophical apparatus was to figure in the workshop's repertoire following 's Gravesande's arrival in Leiden some decades later, one is tempted here to try the following argument. Experimental science in the late seventeenth century was still in its infancy, providing too thin a line of business for an instrument maker to make a living. As we shall see, the Marburg documents record Musschenbroek's success in creating and exploiting this growth market. Several physical instruments sent to Marburg were not yet listed in the catalogue (see Table 2 in section 6), while three "new experiments" added to the air-pump (see section 6) and the percussion apparatus (see section 6) further indicate that, indeed, Musschenbroek's repertoire in this field was growing during the 1690's.

Yet, one should not push this argument so far as to imply that Musschenbroek himself was intent on specializing on this new area of experimental physics at the expense of the production of medical and practical everyday goods. Forty years later, when the cooperation with professor 's Gravesande had borne fruit and the workshop's trade catalogue held well over a hundred pieces of apparatus for research and demonstration, the workshop continued to offer aids for numerous physical ailments.[28]

6. Instruments sent to Marburg

Facts and figures

Dorstenius' letters have not been preserved, but from Musschenbroek's first letter we can infer that around the summer of 1693 Dorstenius established contact by asking a price quotation for an air-pump, the obvious foundation of any cabinet of physics at that period. Musschenbroek's letters and invoices – first in Dutch, later in the then common international language, French[29] –

[28] See the trade catalogue of 1736 (n. 25).

[29] Musschenbroek's French is adequate but certainly not faultless, as he himself admitted in his letter of 11 May 1695: "Mons^{r} me faut pardonner que je n'ecrit pas bon francois." I made no attempts to correct his French in the quotations given in this article.

show that five consignments were sent in the years 1694 to 1696; a small sixth delivery followed in 1703. These are presented in the following tables. For several instruments Musschenbroek added notes and drawings as instructions for use, and these will be brought into the discussion of the instruments further on.

Dorstenius, whose teaching duties included surgery, also bought some medical appliances, which loomed large in Musschenbroek's repertoire. These are included in the following tables, but will not be discussed as they are related not to research and demonstration but to practical medicine. Books were also sent, and these will be discussed in section 7.

Table 1 – Dates, quantity and prices of Musschenbroek's export to Marburg

The number of items (instruments and accessories) are given by approximation: counting scientific apparatus always involves interpretation. Multiple entries in one invoice, such as 'two hydrometers' or '17 slides for the magic lantern' have been counted as one. Transport and packing costs have been subtracted where known. The prices are given in Dutch guilders and stuivers, 1 guilder being 20 stuivers.

Delivery	Date	Number of items	Price
A	4-3-1694	25	265-17
B	20-9-1694	9	110-2
C	11-5-1695	13	169-2
D	28-7-1696	7	81-4
E	12-12-1696	5	38-1
F	26-10-1703	3	29-10
	total	62	693-16

Table 2 – Exported instruments and accessories arranged systematically

The descriptions are not taken verbatim from the invoices, but are given in modern terms and incorporate information from the accompanying documents. To reduce the number of references further on, the date of delivery (A to F as in Table 1) and the corresponding entry in the 1694 trade catalogue (appendix) are given here between brackets; '-' means that an instrument is not mentioned in the catalogue. Prices are given as charged; differences between the invoices and the catalogue are passed without comment.

PNEUMATICS		
Horizontal air-pump with set of accessories as described and illustrated in pamphlet	(A/2)	189-16
Glass to show isotropy of the air	(D/-)	2-0
Clockwork in vacuo	(F/-)	15-0
MECHANICS		
Percussion apparatus with two wooden balls	(C/postscript)	32-0
HYDROSTATICS		
Syphon fountain	(A/-)	7-10
Brass cube to weigh water	(A/5)	15-15
2 glass hydrometers	(B/-)	2-10
5 metal spheres for Archimedes' experiment	(B/-)	16-0
Brass cylinder to demonstrate water pressure	(B/6)	50-0
2 glass tubes with Cartesian divers	(B,C/-)	20-15
OPTICS		
3 glasses for a camera obscura	(C,D,E/-)	9-6
Magic lantern with total 93 slides	(D,E,F/-)	73-18
4 French prisms	(D/-)	7-4
OTHER PHYSICAL INSTRUMENTS		
Aeolipila (steam jet)	(A/7)	3-3
Thermometer	(B/-)	1-10
Speaking tube	(C/-)	12-12
Armed lodestone lifting ½ pound	(E/-)	8-10
Barometer (sold without the mercury)	(F/-)	12-10
MICROSCOPES		
2 microscopes each with 6 ground lenses	(A,C/15)	37-16
2 aquatic microscopes and 3 extra lenses	(C,D,E/-)	19-10

ANATOMY AND PHYSIOLOGY		
2 syringes with 8 tubes each	(A,C/8)	40-10
Apparatus to demonstrate valves in plants	(B/3)	13-10
Apparatus to demonstrate respiration	(C/4)	4-0
Blow-pipes	(C/11)	3-15
Double tap and pipes	(D/9)	7-10
Two muzzles for live experiments	(A,D/13)	7-3
MEDICINE		
Instrument for blood transfusion	(A/10)	2-2
2 silver flexible catheters	(A/18)	9-0
Clyster apparatus c.a.	(B/21,22,23)	12-12
2 silver catheters, one for each sex	(B/19,20)	9-0
Truss for the incontinent	(C/27)	9-9
Horn-shaped hearing aid	(C/-)	12-12
Instrument for tooth-ache	(C/-)	2-10
'Glossocomium' for splinting a broken arm	(C/-)	31-10

The horizontal air-pump and its printed description

On 22 September 1693 Musschenbroek offered "the smallest type of air-pump" with equipment. A complete set cost Hfl 175: Hfl 94 for the pump, the remainder for specified accessories. Musschenbroek wrote that he always added a drawing and description, but when half a year later he actually sent the pump with accessories, these manuscript instructions were not sent along. Instead he announced that he had a pamphlet printed and would send it upon completion in a week or two. Thus we can date the enclosed *Descriptio antliae pneumaticae et inst[r]umentorum ad eam inprimis pertinentium* to the spring of 1694.[30] It consists of six text-pages explaining the pump and its accessories, which are shown in three double-page engravings measuring 21 by 33 centimeters (Figs. 1, 2, 3). Plate I shows the pump, its barrel screwed horizontally on a wooden base which in its turn could be clamped on a table. Its three-way tap is shown below it in detail (N). Four spanners, used among others to operate the tap, are shown in plate II. The tube extending from the tap was threaded at (F), to accommodate either a base-plate (as shown) or mounted receivers, which were screwed on. Plates II and III show the accessories for experiments, which came with the pump and were specified each with its price in the invoice; these are discussed further on.

[30] The only other copy known to me is in the Utrecht University Museum.

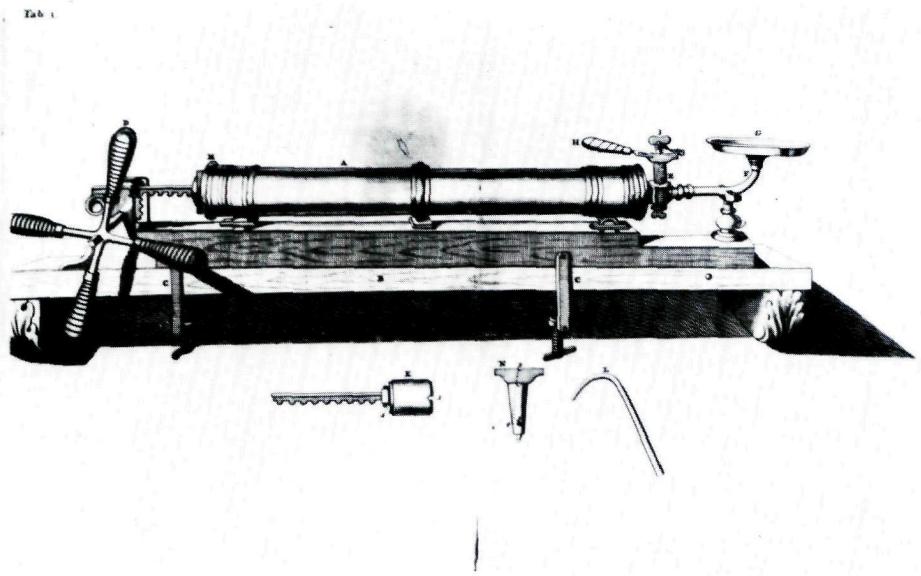

Figure 1 – Musschenbroek's horizontal air-pump. *Descriptio antliae pneumaticae* ... (1694), Plate 1

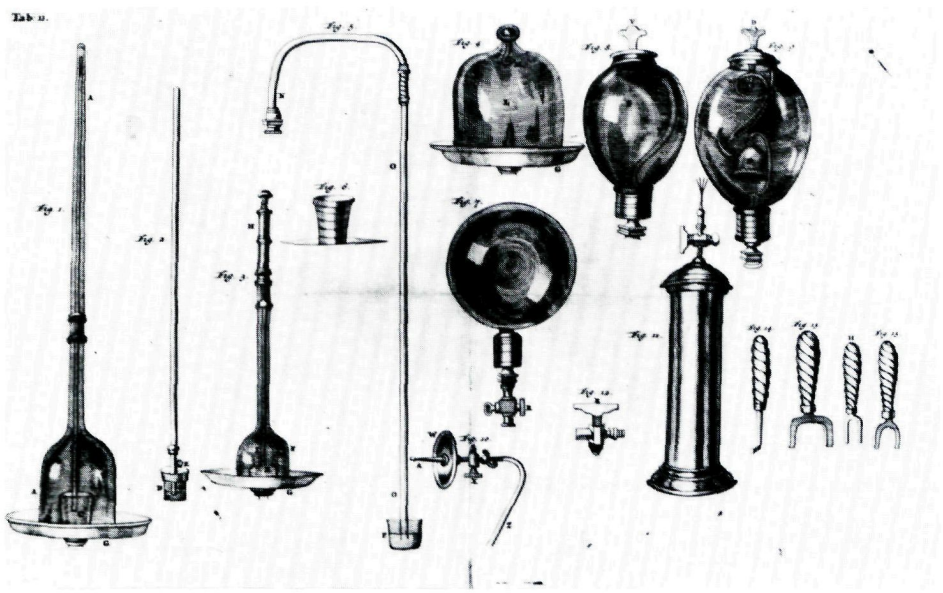

Figure 2 – Accessories to the horizontal air-pump. *Descriptio antliae pneumaticae* ... (1694), Plate 2

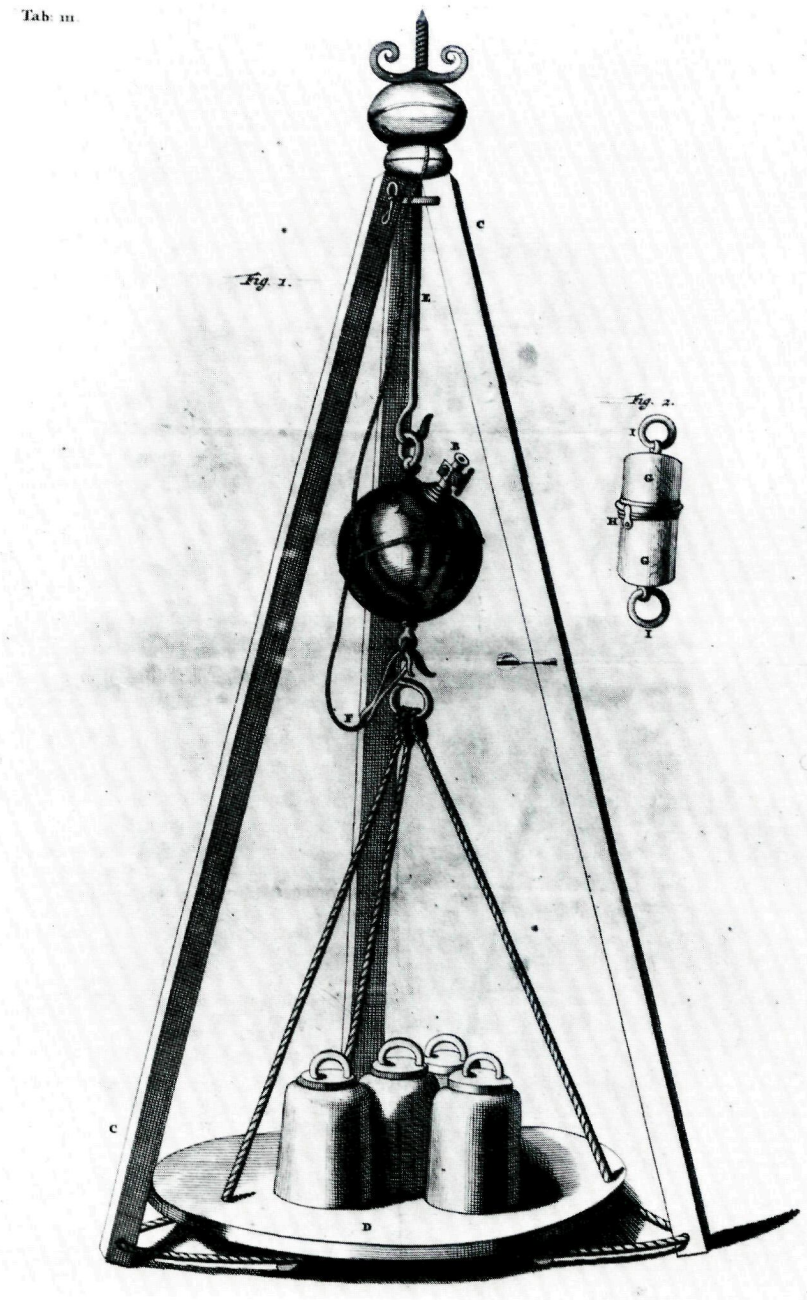

Figure 3 – Magdeburg hemispheres suspended from tripod and marble cylinders for cohesion experiments. *Descriptio antliae pneumaticae* ... (1694), Plate 3

The Musschenbroek workshop is usually associated with an air-pump with inclined cylinder (Fig. 4). A first, rather crude version of that diagonal pump was constructed in 1679 to the design of the Leiden professor Wolferdus Senguerdius and illustrated the following year in his *Philosophia naturalis*.[31] That these were a successful product of the Musschenbroek workshop is suggested by the survival of at least five copies, dated between 1686 and 1708.[32] This stands in marked contrast to the horizontal air-pump, of which only one copy survives, and even this one has at some stage been brought into a diagonal position (Fig. 5).

Yet there is circumstantial evidence, which I shall give in chronological order, that Musschenbroek's horizontal air-pump was not all that uncommon. When a revised edition of Senguerdius' book appeared in 1685, it not only treated a modified version of the diagonal model in great detail, but also contained an engraving of a horizontal air-pump.[33] Also in 1685 a tract on pneumatics was published in Dordrecht, which shows a small horizontal air-pump and Magdeburg hemispheres suspended from a tripod, exactly as in Musschenbroek's later pamphlet.[34] In 1686, Johan van Musschenbroek had his portrait painted by Pieter van Slingeland and chose this pump as a requisite (Fig. 6).[35] That same year saw the publication of James Dalrymple's *Physiologia nova experimentalis*, and this again shows the horizontal air-pump; in the text, the Scottish author specifies that he has such a pump from Musschenbroek, "the very skilled artificer," and considers it the most convenient of all models.[36] Some years

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[31] Wolferdus Senguerdius, *Philosophia Naturalis Quatuor Partibus* (Leiden: Daniel a Gaasbeeck, 1680), p. 169. The construction date is given in Wolferdus Senguerdius, *Rationis atque experientiae connubium* (Rotterdam: B. Bos, 1715), p. 4: "ut mihi construeretur, Anno 1679 cum Artifice conveni."

[32] Daumas (n. 3), *Scientific instruments*, p. 85 and Plate 55. To the three copies he mentions (Leiden 1698, Utrecht 1706 and Munich 1708) two may be added: Kassel (1686) and Domus Galilaeana, Pisa (1697).

[33] Wolferdus Senguerdius, *Philosophia naturalis* (Leiden: Daniel a Gaesbeeck, 1685[2]), preface and opposite p. 267 (diagonal model) and p. 256 (horizontal model).

[34] *Wiskonstige betooging van de verdunning en verdikking der lugt ... Uyt de gronden van de Heer Renatus des Cartes opgeheldert, en door eenige experimenten nader bevestigt* (Dordrecht: Wed. van Jasper en Dirck Goris, 1685). I owe this reference to R.H. Vermij in Utrecht.

[35] The painting is part of a collection of Musschenbroek portraits in the possession of a descendant, Mr. J.L. Bienfait, Aerdenhout, who kindly provided me with the photograph reproduced here. It is unsigned, but the companion portrait of Johan's wife Margaretha van der Straaten has on the back 'P.v.Slingeland pinxit 1686'. F. Muller, *Beschrijvende catalogus van 7000 portretten van Nederlanders* (Amsterdam: Frederik Muller, 1853), p. 181, suggests that it is a later copy. Rooseboom (n. 2), *Bijdrage*, p. 106, mentions two other portraits of Johan Joosten van Musschenbroek by Pieter van Slingeland.

[36] James Dalrymple, first viscount Stair, *Physiologia nova experimentalis* (Leiden: apud Cornelium Boutesteyn, 1686), Plate III, fig. 9. I owe this reference to R.H. Vermij in Utrecht. On p. 599 Dalrymple writes: "haec nobis videtur omnium commodissima quae a Mutsenburgio Leidensi, artifice peritissimo fabricatur, vid. tab. 3, fig. 9."

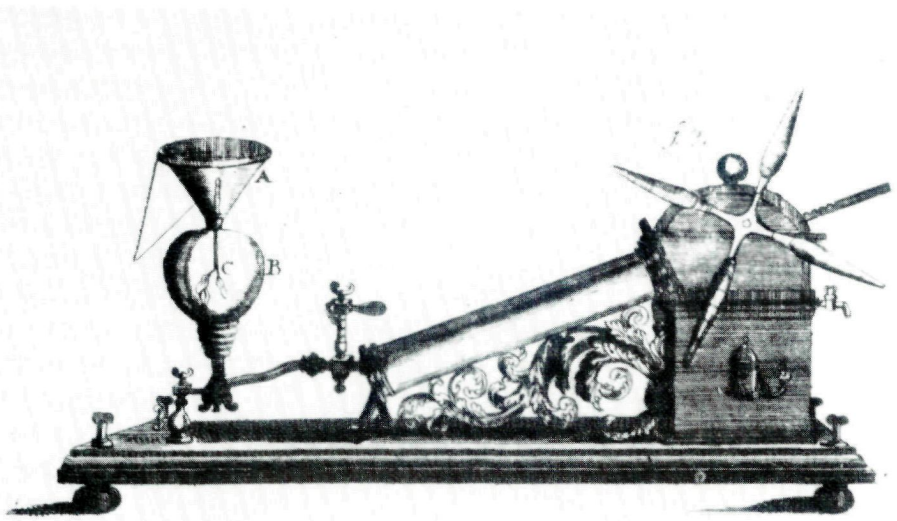

Figure 4 – Musschenbroek's diagonal air-pump as designed by Wolferdus Senguerdius in the 1670's. Note the workshop's trade mark, the burning oil-lamp, on the pedestal. The experiment with the plant hanging upside down in the receiver was intended to demonstrate the presence of valves in its stem. B.M. von Valentini, *Neu-aufgerichtetes Rüst- und Zeughaus der Natur* (Frankfurt, 1714), Plate 19, fig. 7

later these last words were echoed by Stephan Chauvin, a French Huguenot immigrant in Rotterdam, in his philosophical encyclopaedia.[37] As an emblem of experimental science, horizontal air-pumps also appear on the frontispieces of several Dutch publications of the period.[38] Finally it may be noted that of five air-pumps owned by Petrus van Musschenbroek, one was the small horizontal

[37] Stephanus Chauvin, *Lexicon rationale sive thesaurus philosophicus* (Rotterdam: apud Petrus van der Slaart, 1692). The pump is shown on Plate VIII, fig. 9; the corresponding (unpaged) text s.v. *Machina pneumatica* starts: "The air-pump comes in several shapes, used and described by others; but the one shown here seems to us the most convenient (*commodissima*) of them all."

[38] A rather oversized copy is shown in the elaborate frontispiece in Chauvin (n. 37) and in B. Nieuwentijt, *Het regt gebruik der wereltbeschouwingen* (Amsterdam: By de Wed. J. Wolters, en J. Pauli, 1715). A more accurate depiction of the Musschenbroek pump appears on the frontispiece of a book by the Franeker professor W.G. Muys, *Elementa physices methodo mathematica demonstrata* (Amsterdam: Apud Janssonio-Waesbergio, 1711).

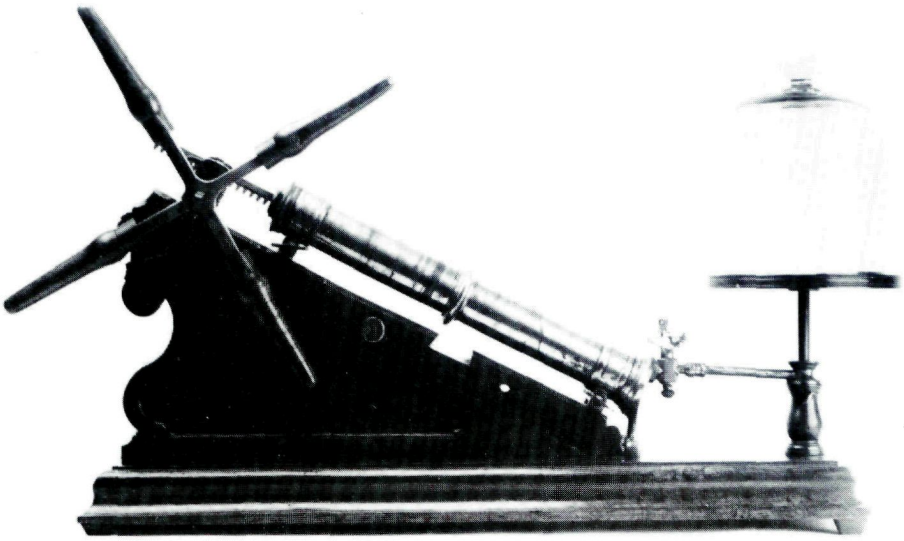

Figure 5 – Single-barrel air-pump, made in the Musschenbroek workshop around 1700; barrel length 40 cms. Two holes in the wooden base, exactly corresponding to the ones which served to clamp the horizontal model to a table, indicate that it was originally a horizontal air-pump. Museum Boerhaave, inv.nr. 9551 (formerly L2a)

model with its accessories as built by his father.[39]

Already in the 1680's then the small horizontal air-pump was available from the Leiden workshop and it was to remain fairly common for some time. When he gave Dorstenius some details on how to order and pay his air-pump, Musschenbroek stated that he had constructed many copies[40] and, as we have seen, he even issued a pamphlet for future customers. This episode shows Musschenbroek, as discussed in section 5, as an innovative entrepreneur creating and exploiting the growth market of experimental physics. By the late seventeenth

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[39] Auction catalogue *Collectio exquisitissima instrumentorum in primis ad physicam experimentalem pertinentium, quibus, dum vivebat, usus fuit ... Petrus van Musschenbroek* (Leiden: apud Samuelem et Johannem Luchtmans, 1762), items 481 and 482.

[40] Letter 22 September [1693]: "Hier mede gaat hier onder een specificatie van de kleinste soort van lugtpompen of Antlia Pneumatica, nevens de naaste prijs. UE. diende het hier of van een Amsterdams Coopman te laten afhalen en most mij hier in holllands gelt betalen alsoo geen occasie heb om het in Duitslant te senden. en heb nu soo veel gemaakt maar heb noyt verder gelevert als aan een Coopman, die dan ordre had om mij te betalen en het dan ook wegsondt soo dat op soodanigen manier altijt deselve verkoop en pak deselve in kissies en sende een teykening met een descriptie daarbij."

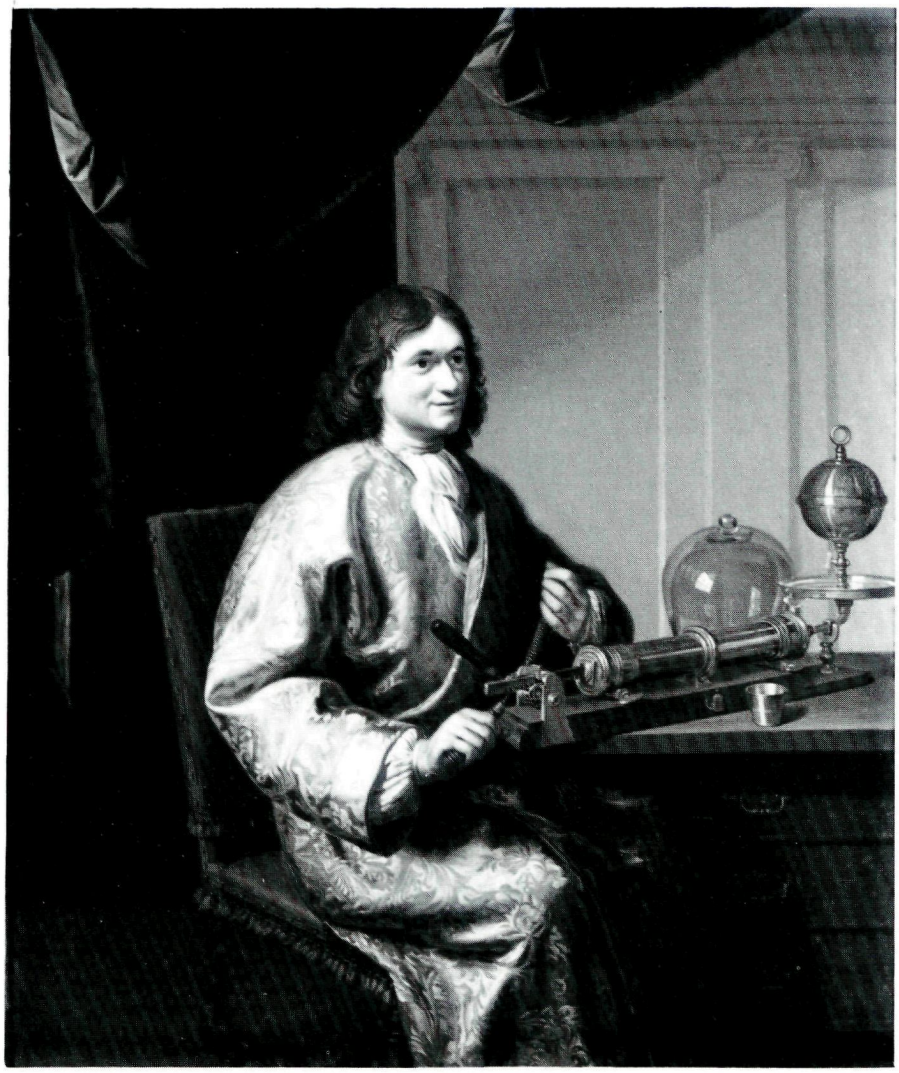

Figure 6 – Johan Joosten van Musschenbroek (1660-1707) with his horizontal air-pump. Oil on panel, 44 x 36 cms., by or after Pieter van Slingeland, 1686. Collection J.L. Bienfait, Aerdenhout. Photo Iconographisch Bureau, The Hague

century the air-pump had lost the exclusiveness it had had in the 1660's.[41] There was a potential market for relatively simple and cheap models, and Musschenbroek's small horizontal model clearly supplied a want. It was smaller and simpler in design, lacking some of the sophistication of the diagonal model; thus, its horizontal position did not allow to float water on the piston to ensure its air-tightness while pumping. The crucial difference was of course its price: according to the 1694 catalogue 'the large type of air-pump' with all accessories cost Hfl 500, as against Hfl 175 for the small version bought by Dorstenius.

Pneumatic experiments

An instrument maker wishing to promote the sale of his air-pump was well advised to inform his patron of the possible experiments that could be performed with it and, of course, to supply the necessary apparatus. Musschenbroek's *Descriptio antliae pneumaticae* (see above) described and illustrated a variety of accessories with which to conduct pneumatic experiments. We note several barometric experiments (Fig. 2, *1*, *2*, and *5*); simple bell-jars to be placed on the base-plate (*4*) as well as receivers of various shapes mounted in brass to be screwed onto the tube (*7*, *8* and *9*); and a brass air-pressure fountain (*11*) which Musschenbroek claimed could spout water to a height of 25 feet.

Three of these accessories had not been specified in the original quotation sent to Dorstenius half a year earlier and ordered and paid for in advance. These were the brass cone to break a plate of glass in vacuo (Hfl 2-10) (*6*); 'the small clock to strike inside the glass' (Hfl 6) to demonstrate that sound does not travel in a vacuum (*9*); and 'the anatomical experiment with 2 pipes' (Hfl 6-6) with which mercury or another fluid could be made to flow into arteries under reduced atmospheric pressure to make the capillary vessels visible (*10*). In his accompanying letter, Musschenbroek explained that these were "new experiments." Evidently Musschenbroek had only just added these to his repertoire, and he took the liberty of throwing them in as well, "since you wrote that I should add everything which you would require."[42]

In 1695, the programme of lectures offered at Marburg University first mentions Dorstenius' treatment of the air-pump.[43] In 1696 appeared Dorste-

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[41] Steven Shapin & Simon Schaffer, *Leviathan and the air-pump. Hobbes, Boyle, and the experimental life* (Princeton: Princeton UP, 1985), chapter 6. Oddly, the authors claim that the earliest surviving air-pumps are of early eighteenth-century manufacture (p. 227). From the Musschenbroek workshop alone at least four seventeenth-century air-pumps survive: see *supra* (n. 33) and De Clercq (n. 8) *The Leiden Cabinet of Physics*, pp. 14-17.

[42] Letter 4 March 1694: "Heb nog 3 nieuwe experimenten daarbij gedaan, dewijl Ue. schreef dat alles daarbij sou doen, dat Ue. nodig had." They are specified on the invoice.

[43] Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, p. 54.

nius' only publication on a physical subject, *Dissertatio physica de vacuo*. It reports on experiments with the two accessories shown in Plate III of the pamphlet: the Magdeburg hemispheres suspended from a tripod and the set of polished marble cylinders for cohesion experiments (see Fig. 3).[44] Regarding these marble cylinders, Musschenbroek had claimed in his pamphlet that they could hold a suspended weight of almost 800 pounds. Valentini, either through inaccuracy or wilful exaggeration, here gives the unlikely figure of 8000 pounds![45]

In his pamphlet, Musschenbroek stressed that the owner of an air-pump was not restricted to the pneumatic experiments of the natural philosopher.The instrument could also profitably be used in chemistry, medicine, anatomy and botany. A case in point is a plant experiment for which Musschenbroek sent the necessary equipment together with a drawing and instruction for use. As shown in Fig. 4, an uprooted plant was placed upside down in a glass receiver, its roots sticking into a brass funnel screwed on the glass and filled with water. When some air was pumped out of the receiver, the water could be seen creeping through the plant toward its top. It proved impossible to reverse the sap-current by turning the plant and repeating the experiment and this, Musschenbroek wrote, demonstrated that there were valves preventing the plant from loosing the nutritients it had transported upward.

It may be noted here that if Musschenbroek's instruments were neutral enough, his suggested experiments and interpretations could, of course, be controversial. Thus Valentini (who incidentally used mercury instead of water) approved of this way of showing upward sap-currents, but was unconvinced by the downward half of the experiment.[46] Papin, who had performed a similar experiment in the 1670's, did not deny the presence of valves, but concluded that in this case they played no role.[47] It was up to the patrons, like Dorstenius, to remain aware that you could buy glass and brass, but no incontestable truths.

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[44] Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, pp. 136-137.

[45] Valentini (n. 14), *Rüst- und Zeughaus*, p. 7: "... nicht mit 8000 Pfund ... von einander reissen [kann]."

[46] Valentini (n. 14), *Rüst- und Zeughaus*, p. 12: "Ob man aber hiermit auch zeigen könne dass in den Röhrlein oder Aederlein der Kräuter auch Vorschläge oder *valvulae*, wie in denen lebendigen Thieren seyen, solches kan vor gewiss noch nicht behaupten, wiewohlen es Prof. Senguerd in Leyden und aus desselben Beybringung Herr Muschenbroek in Beschreibung seiner Lufft-Pumpe ohngescheuet vorgeben." Senguerdius gives this experiment in his *Philosophia naturalis* (1685^2, see n. 33), in Ad Lectorem, referring to Plate II. Valentini's reference to Musschenbroek's description of the air-pump is puzzling: the *Descriptio* ... of 1694 only hints at the possibility of using the pump for experiments on the *circulatio humorum* in plants, without going into details.

[47] Denis Papin, *Nouvelles expériences du vuide* (Paris, 1674), as reprinted in *Oeuvres complètes de Christiaan Huygens*, vol. 19 (La Haye: Martinus Nijhoff, 1937), pp. 216 and following. The experiment is given on pp. 229-230.

Percussion apparatus

Below his trade catalogue (see appendix) Musschenbroek wrote: "Mr. de Volder has an instrument to show the laws of movement, which is very handsome, costs about 60 guilders."[48] The wording suggests that professor Burchardus de Volder had built this percussion apparatus himself, or had bought it elsewhere, so that in this case Musschenbroek drew on the university collection to enlarge his repertoire. Dorstenius ordered one straight away, but Musschenbroek did not sell this kind of apparatus off the shelf,[49] and it was not until May 1695 that "l'instrument pour le choc du corps" was dispatched to Marburg. Musschenbroek, who sent a description with drawing (Fig. 7), specified that it was to be hung on the wall and was fitted with graduated brass arcs, along which the effect of collision of the two suspended ivory balls could be read off. It cost Hfl 30, only half the original tentative quotation. Had Musschenbroek overestimated the job? His accompanying letter suggests a better explanation. He had sent the instrument with two hard-wooden balls, costing one guilder each. The much harder ivory, as given in the instruction, would be better, he wrote, but these were easily twenty guilders, and Musschenbroek probably knew that Dorstenius had to be economical. But he added with proper business acumen: "if Monsieur wishes the ivory balls I shall gladly have them made."[50]

Hydrostatics

Of the six types of hydrostatic apparatus bought by Dorstenius in 1694 and 1695, only two had been mentioned in the catalogue. One was a brass container to determine the weight of half a cubic foot of water, based on Archimedes' principle; the other is discussed below. Novelties were a syphon fountain (Fig. 8); two glass hydrometers graduated by small globules of glass projecting from

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[48] For De Volder's own percussion apparatus see De Clercq (n. 8), *Leiden Cabinet of Physics*, p. 27.

[49] Letter 20 September 1694: "L'instrument pour les loix de mouvement n'est pas encore fait et depuis que je n'avoit point de temps en une mois je n'osoit pas attendre si longtemps pour l'hiver et je le fera si tost qu il me sera possible."

[50] Letter 11 May 1695: "J'ay seulement pendu 2 boules du bois dur. L'yvoire est mieux parce quils sont plus dur, mais ils sont fort cher, ils voudrent bien 20 florin pour les deux. et vous pouvez toujours laisser faire ... Si Mons[r] desire les boules d'yvoire je laisseray bien faire." The invoice breaks the apparatus down as "L'instrument pour le choq du corps" (Hfl 30) and "les 2 boules" (Hfl 2). Valentini, in his compiled list of Musschenbroek's instruments (see section 3), renders this as "*Hugenii Chronoscopium*" (Hfl 30) and "Die zwey helffenbeinerne Kugeln darzu" (Hfl 2). The fact that he gave the price of the wooden balls but specifies the balls as made of ivory (German: elfenbein) suggests that he saw Musschenbroek's instruction for use and the invoice, but not the accompanying letter. The designation of the instrument as *Hugenii Chronoscopium* brings to mind Christiaan Huygens' contribution to the formulation of the laws of collision.

the stem; two glass tubes with Cartesian divers; and a set of five spheres of lead and brass (pure and in various mixtures), with plaster models of the same size. This set was used with a pair of scales to re-enact Archimedes' celebrated exposure of the adulteration of a crown. Musschenbroek originally dispensed with an explanation, but apparently Dorstenius never really found out how to use it, because in 1702, eight years after delivery, Musschenbroek sent a hand-written instruction covering several pages.[51]

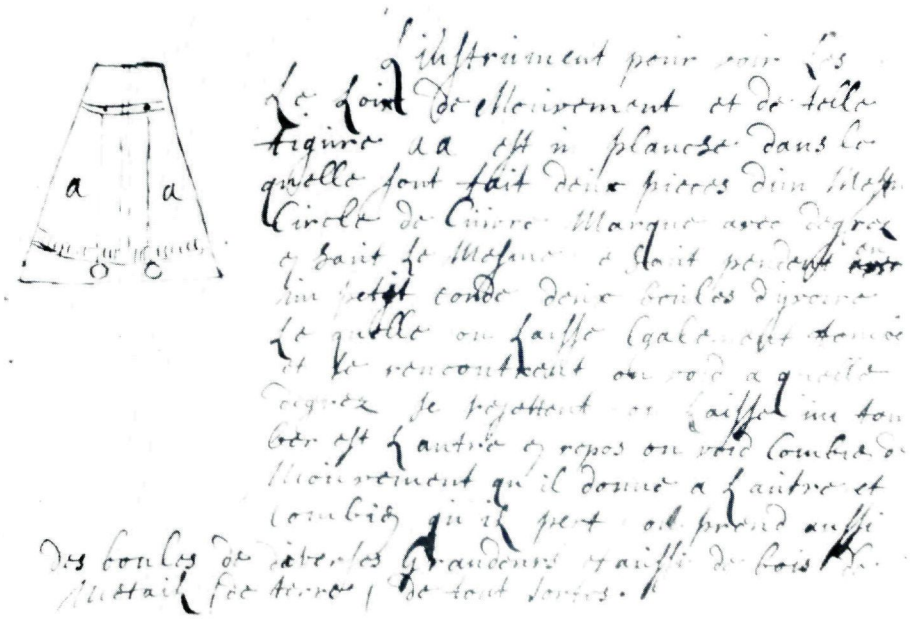

Figure 7 – Musschenbroek's drawing and description of his percussion apparatus, as dispatched to Marburg in May 1695

The tallest instrument exported to Marburg was the 'brass cylinder', dispatched in September 1694 with directions for use and a drawing headed "Le Cilindre

[51] Musschenbroek evidently knew the well-worn story of Archimedes' discovery of the principle of specific gravity, but confused King Hieron with the proverbially rich King Croeses: "C'est sur la mesme methode que Archimedes trouvoit combien de l'argent que l'ouvrier avoit melé dans la couronne qu'il avoit fait pour le Croses sans rompre la couronne car le Roij ne voudroit pas a cause qu'il estoit si injoineusement fait."

de Mons[r]. le Prof. de Volder" (Fig. 9).[52] The instrument consisted of a one foot high brass cylinder, which instead of a fixed bottom had a loose brass disk six inches in diameter. To this disk, a chain was attached which ran upward through the cylinder and a six-feet brass pipe and was connected to the arm of a balance. First one determined the weight required to lift the disk, which was sealed with wax. Then water was poured into the cylinder and the pipe; to keep the disk in place while filling, it was held pressed to the bottom from below. By repeating the weighing operation the pressure of water columns of up to seven feet could be determined to demonstrate the hydrostatical paradox. Alternatively, the instrument could also serve as a rather crude hydrostatic bellow: by unscrewing the lid on the cylinder one could demonstrate that water pressure could lift weights placed on top of that lid.

Optics

Among Dorstenius' acquisitions were four prisms to treat the properties of light in his lectures on experimental physics, which Musschenbroek had imported from France.[53] He also had two classics of recreational science, which may have been a draw to his lectures, the camera obscura and the laterna magica. Of the first we are not told how and when he acquired it; Musschenbroek only sent him three lenses of different focal distances.[54] The magic lantern arrived in July 1696, with delay because of problems in the production of the slides (for which see section 8); Musschenbroek claimed that, with a projection distance of twenty feet, the image was easily six feet tall.[55]

Barometers

Commercial production of barometers began in England in the late seventeenth

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[52] The wording suggests that, as with the percussion apparatus discussed above, De Volder either had a hand in its design or acquired it elsewhere. The instrument was in the university collection in 1705, see De Clercq (n. 8), *The Leiden Cabinet of Physics*, p. 33. Valentini's discussion of what he calls *Volderi Cylinder* seems to have been taken straight out of the Marburg manuscripts: *Rüst- und Zeughaus*, pp. 43-44 and Plate 29, fig. 2.

[53] Letter 28 July 1696: "4 Prismata sont les plus beaux que j ay puis trouver, car ils viennent de france en [=et] on ne puis pas avoir de si beaux qu avant la guerre." The implications of this last statement are discussed in section 8.

[54] Letter 11 May 1695: "Encore une verre pour le camera obscura environ de 3 ou 4 pieds de distance" (Hfl 3-3); 28 July 1696: "Une verre pour une chambre obscure de 7 ou 8 pieds, vous trouverez bien la distance" (Hfl 3); 12 December 1696: "Encore une verre qui est tres bonne pour une camera obscure. Il est encor mieux que cette que j'ay envoye le dernier le distance est environ 7 pied" (Hfl 3-3).

[55] Letter 28 July 1696: "quand on est 20 pied de la muraille les figures presentent bien 6 pied grand."

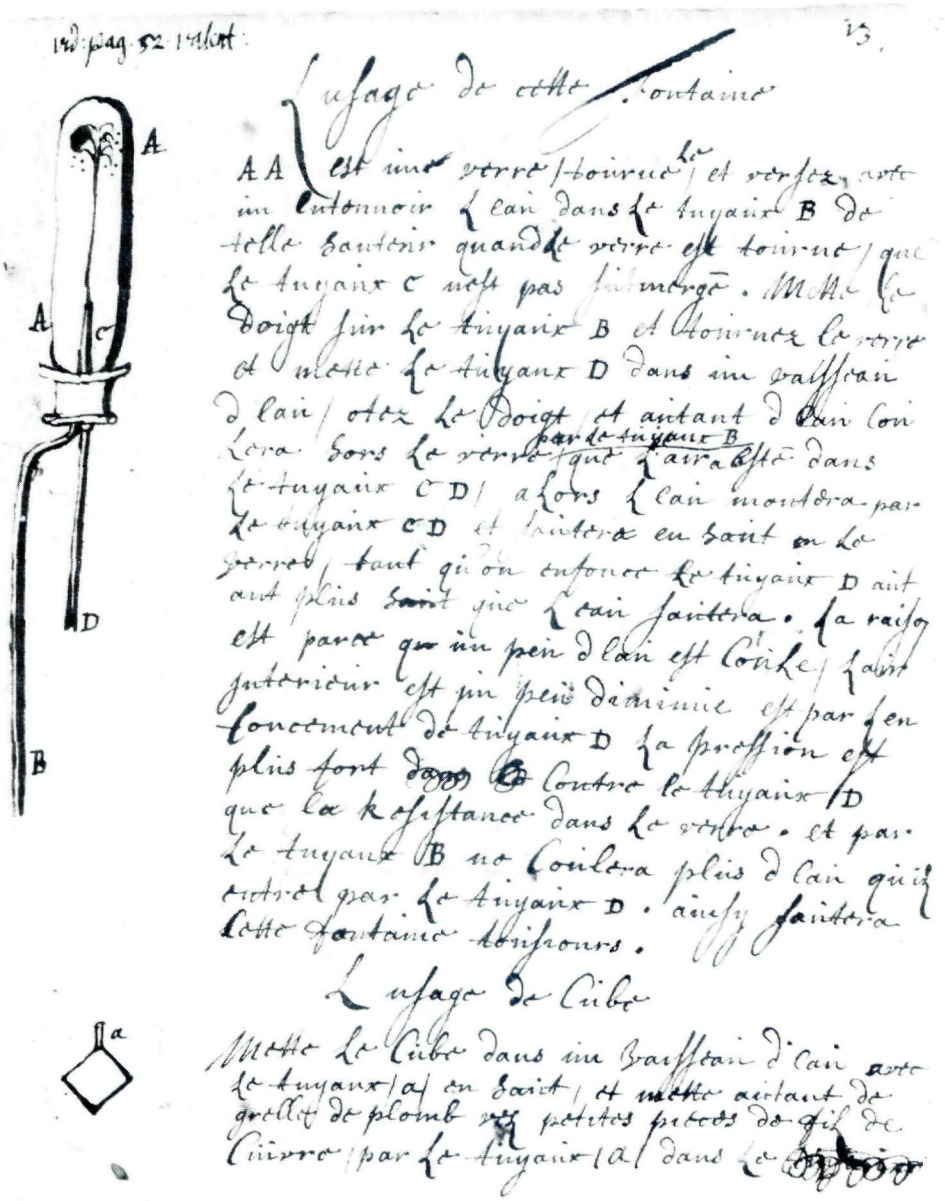

Figure 8 – Musschenbroek's drawing and description of his syphon fountain, as dispatched to Marburg in September 1694. The note 'vid:pag. 52, valent:' in the top-left corner refers to a discussion of this instrument in Valentini's *Neu-auffgerichtetes Rüst- und Zeughaus der Natur* (Frankfurt, 1714), p. 52

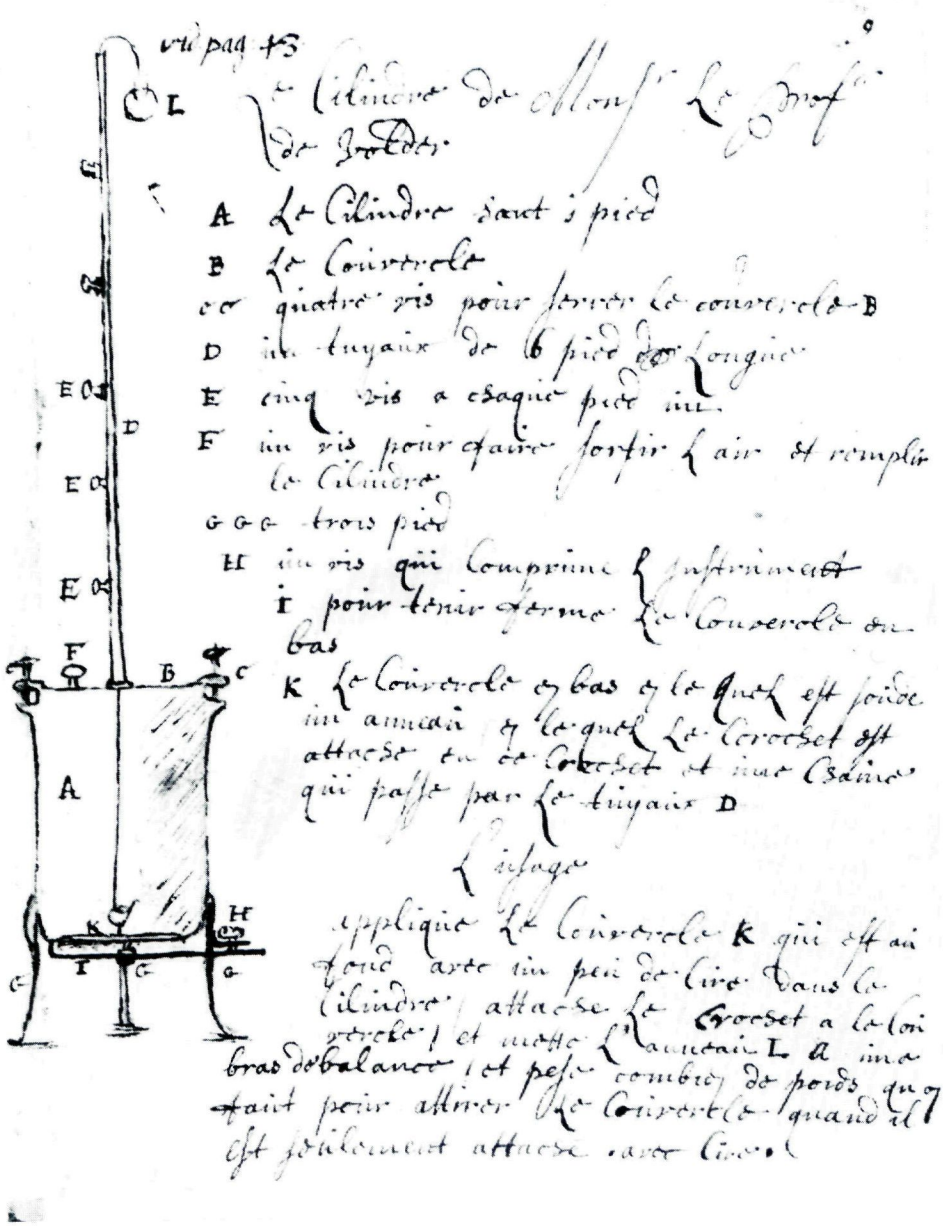

Figure 9 – Musschenbroek's drawing and description of his hydrostatic cylinder, as dispatched to Marburg in September 1694. For the note in the top-left corner see the caption to Fig. 8

century; the continent followed in the eighteenth century.[56] In the Netherlands the Musschenbroek workshop is known to have made barometers, of which two signed but undated copies survive.[57] When production began is unknown. In 1711 Uffenbach noted that Jan van Musschenbroek had barometers 'of the common type'; in 1736 he was still mentioned in one breath with Fahrenheit and Prins for his excellent barometers.[58]

From the Marburg documents we learn that the production had already been started by his father. Evidently Dorstenius, after an interval of some five years, had resumed contact asking a price quotation for a barometer. On 3 March 1702, Musschenbroek answered that he made them for 22 guilders, but that although they were portable he would send one empty (and obviously cheaper) for fear of breakage in transport. When the barometer was finally sent in October 1703, Musschenbroek included a curved brass pipe with instructions for filling. He did not add the mercury since he thought Dorstenius could have it cheaper at home, where it came from. Later, Dorstenius wrote that he had trouble with the instrument: the mercury kept dropping below the graduated plates. On 28 January 1704, Musschenbroek advised him to check if air was admitted into the glass through a crack. Tubes, he explained, sometimes crack spontaneously since they cannot be placed in the oven as other glass-ware. The other possible reason he could think of was that the wooden reservoir, into which the tube was cemented, had not been filled sufficiently, and to remedy this Musschenbroek added a detailed instruction.

Other physical instruments

In his correspondence, Musschenbroek at times gave credit to the designer of an instrument, such as the Leiden professors De Volder (see above) and Senguerdius (see below) and the Delft physician Reinier de Graaf.[59] The only design he claimed for himself was a speaking tube, which he had made, presumably by a white-smith, after his own invention.[60] We are not told in what his improved

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[56] Bert Bolle, *Barometers in beeld* (Lochem-Poperinge: De Tijdstroom, 1983), pp. 17-18.

[57] These are in the Museum Boerhaave (signed 'Musschenbroek Fecit') and the Utrecht University Museum, on loan from the Centraal Museum, Utrecht (signed with the workshop's trade-mark).

[58] Uffenbach (n. 13), *Merkwürdige Reisen*, p. 432: "Barometron, ist nach gemeinem Schlag"; Petrus van Musschenbroek (n. 25), *Beginselen der Natuurkunde*, p. 599.

[59] This was the clyster apparatus described in the catalogue as made "after the invention of Doct[r] de Graaf," on which see William Brockbank and O.R. Corbett, "De Graaf's *Tractatus de Clysteribus*," *Journal of the History of Medicine and Allied Sciences* 9, 1954, pp. 174-190.

[60] Letter 11 May 1695: "La trompette à parler de loin j'ay fait faire de ma propre invention car ordinairement on ne fait pas bien en hollande. l'embouchoir est dans le coffre qu'on applique facilement comme Mons[r]. verra bien."

design of this sound-amplifyer consisted. Did he already give them the shape of a parabola of revolution, as his son Jan was to make them later according to 's Gravesande's calculations?[61]

Two further physical instruments exported to Marburg were a thermometer, whose scale was read with the use of two brass rings,[62] and an armed lodestone, costing 8½ guilders and lifting half a pound. Apparently Dorstenius had wanted a stronger magnet, but Musschenbroek impressed upon him that it would cost accordingly. The really strong ones went for exorbitant prices – one lifting 24 pounds had gone as high as a thousand guilders –, whereas one which had fetched only five guilders at a recent auction he had decided not to buy since he considered it overpaid.[63] In the case of these magnets, Valentini's borrowing from Dorstenius' correspondence (see section 3) led to an absurdity. While it is obvious that Musschenbroek reported on transactions he had witnessed as an outsider, Valentini records even the thousand-guilder magnet as available from the Leiden workshop.[64]

Microscopes

We have seen that the Marburg documents give new insight into the workshop's production of air-pumps. The same applies for the other instrument with which the Musschenbroek workshop is usually associated for the pre-'s Gravesande period: its single-lens microscopes. Two models are generally known and survive in many collections.[65] One was for low-power magnifications and was fitted with an articulated arm of 'Musschenbroek nuts' to bring the object before the

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[61] W.J. 's Gravesande, *Physices elementa mathematica, experimentis confirmata. Sive introductio ad philosophiam Newtonianam* (Leiden: Petrus & Balduinus Janssonius van der Aa, 1720[1]), paragraph 543. 's Gravesande's own speaking tubes are in the Museum Boerhaave.

[62] Separate instructions, apparently sent with the letter and invoice of 20 September 1694: "Il y a aussi un fort petit thermometre pour disteler ou digirer et pour toutes sortes des choses. de voir les grades de chaleur il y a deux anneaux de cuivre qu on puis mettre sur son degrez qu on veut donner de chaleur. on use aussi pour cuire les oeufs."

[63] Letter 12 December 1696: "Si Mons.r desire une qui puis tenir 3 ou 4 livre il y a souvent fois occasion, mais ils sont fort cher quand ils sont bonne. J'ay veu une qui pouvoit tenir une piece de fer de 24 livre, mais il est vendu pour mille florin d'hollande une qui tenoit 4 livre pour 80 florin. Celuy qui etoit sur vendition de Mons.r Capelle est vendu pour 5 florin il ne valoit pas le moitie, pour cela ne nay pas achetez." On the Van de Capelle auction see *infra*, n. 85.

[64] The *Verzeichnuss* of Musschenbroek's instruments in *Rüst- und Zeughaus* (see section 3) lists: "Ein gefaster Magneth/so 24. Pf. hält ... 1000/ 4 Pf. ziehet ... 80/ ½ Pf. hält ... 8-10."

[65] Both types are described and illustrated in Daumas (n. 3), *Scientific instruments*, p. 44 and Plates 34 and 35 and in Anthony Turner (n. 6), *Early scientific instruments*, Plates 81 and 83.

made his syringes after the design of Reinier de Graaf, physician and anatomist in Delft, who in his *De usu siphonis in anatomia* of 1668 had been the first to figure an injecting syringe of the modern pattern.[76] Later Dorstenius bought an extension to this syringe for cleaning entrails and blood vessels before preparation.[77] He also ordered a large number of small anatomical blow pipes, which were on the workshop's repertoire since Samuel van Musschenbroek had made them for the famous anatomist Frederik Ruysch when he worked in Leiden in the early 1660's.[78] Dorstenius seems also to have been involved in live experiments on dogs, judging from his acquisition of two "smoul schroevers" (muzzles) used to silence the poor animals.

Apart from these tools for practical anatomy, Dorstenius also acquired "2 glasses and 1 tube to demonstrate respiration." Musschenbroek referred his patron to a book by Senguerdius, sent along with the instrument, from which he could learn how to operate it.[79] This book can be identified as *Inquisitiones experimentales*, in which Senguerdius reports on a series of demonstrations he had conducted on the process of breathing in 1687-88.[80] The apparatus was effectively a simulation model of the mechanical action of the lungs, into which fresh anatomical material (animal lungs and bladders) was fitted. Respiration was a central theme of seventeenth- and eighteenth-century physiologists, and Senguerdius' demonstrations seem an echo (albeit less gruesome) of the experiments on artificial respiration conducted on live dogs before the Royal

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[76] F.J. Cole, "The history of anatomical injections," in *Studies in the history and method of science*, ed. Charles Singer (Oxford: OUP, 1921), vol. 2, pp. 285-343, esp. p. 297. The engraving of De Graaf's syringe and accessories is reproduced on p. 299.

[77] Invoice 28 July 1696: "Un double robinet 2 tuyaux flexiles." The function of this piece is not given explicitly, but can be taken from its description in a later trade catalogue (see n. 27, n°. 5): "Een dubbelde kraen met twee pypen om darmen en vaten uyt te spoelen" (Hfl 7-10). It is illustrated in Valentini (n. 14), *Rüst- und Zeughaus*, Plate 18, fig. 1.

[78] Using these pipes Ruysch managed to demonstrate the presence of valves in lymph vessels, causing the lymphatic fluid to flow in one direction only, which he published in his *Dilucidatio valvarum in vasis lymphaticis et lacteis* (The Hague: Ex Officina Harmani Gael, 1665). That Samuel van Musschenbroek had made these "minute pipes" is stated in *Alle de Ontleed- Genees- en Heelkundige Werken van Frederik Ruysch* ... (Amsterdam: Janssoons van Waesberge, 1744), vol. 3, p. 1004. I owe this reference to prof.dr. A.M. Luyendijk-Elshout in Leiden.

[79] Letter 11 May 1695: "2 verres et un tuijaux de cuivre pour les Respiration j'ay envoyé les disputes de Prof[r] Senguerd hors le quels Mons[r] verra l'usage." The invoice has the book as "les experim. de prof[r]. seng." (Hfl 6-6).

[80] Wolferdus Senguerdius, *Inquisitiones experimentales. Quibus, praeter particularia nonnulla phaenomena, atmosphaerici aeris natura explicatius traditur* ... (Leiden: Cornelius Boutesteyn, 1690[1]). I only saw the second edition (Leiden: Cornelius Boutesteyn, 1699), in which see especially Plate 7 showing both glasses and the tube in use. The respiration experiments are treated again, in less detail, in Senguerdius (n. 31), *Rationis atque experientiae connubium*, chapter 18.

Society in the 1660's.[81]

7. Books sent to Marburg

The Musschenbroeks had close ties with the Leiden booktrade through intermarriage with the Luchtmans family, reknowned printers who were to publish both Petrus' and Jan's books.[82] With his consignment of instruments sent in May 1695, Musschenbroek included two books, adding that through his brother-in-law Jordaan Luchtmans he was in a good position to supply his German patron with more books.[83] Dorstenius made use of this, and in the following year a further 29 books were sent. The majority arrived in the summer of 1696. These were mostly new copies, but two French books had not been available due to the war, and Dorstenius had to make do with copies bought at an auction, one of which lacked the plates.[84] The rest followed that winter and had been acquired at an auction of the library of a Leiden minister Josias van de Capelle, organized by Jordaan Luchtmans. Dorstenius had selected these in the auction catalogue, which had been sent to him together with several more copies which he was kindly requested to distribute among his colleagues.[85]

The books sent to Marburg contained many botanical works, but also titles related to Dorstenius' instruments, as Senguerdius' *Philosophia naturalis* and *Inquisitiones experimentales*, Edme Mariotte's *Essays de physique*, *Traité du mouvement des eaux et des autres corps fluides* and *Traité de la percussion ou choc des corps*, and Nicolaas Hartsoeker's brand-new *Principes de physique*

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[81] See for example Diana Long Hall, *Why do animals breathe? Physiological problems and iatromechanical research in the early eighteenth century* (New York: Arno Press, 1981), which does not mention Senguerdius.

[82] See the family tree in Crommelin (n. 1), *Descriptive catalogue*, p. 22.

[83] Letter 11 May 1695: "Si Mons[r] a encor des autres livres besoin j'ay un beau frere qui est aussi un marchand a libraire qui a tout sortes des livres il traitera Mons[r] comme un honneste homme."

[84] The consignment of 28 July 1696 included 19 books, all specified with their price on an invoice headed "De Heer Dorstenius debet aan Jordaan Luchtmans" (Hfl 69-5). The problems encountered in buying the two French volumes are given in Musschenbroek's letters of 28 July and 12 December 1696; the plates were lacking from Mariotte's *Choc des corps*.

[85] Letter 28 July 1696: "Mons[r] Mon beau frere a mis dans le coffre diverses cataloges d'une fort curieuse bibliotheec il vous prie de faire donner par un serviteur a tout les Prof[rs] selon l'addresse et envoyer l'autre paquet a Cassel selon l'addresse Mons[r] obligeroit lui infiniment." The consignment of 12 December 1696 contained ten books (total Hfl 26-13) and a specification by Luchtmans "Gekocht voor swager Mussenbroek uijt de biblioteek van D[r] Capelle." The auction of Josias van de Capelle's library and other collections was held on 24 September 1696 at Luchtmans', see *Catalogus exquisitissimorum in omni studiorum genere librorum ... Josiae van de Capelle. Dum viveret Lugdunis in Batavis Pastoris Ecclesiae Dignissimi facundissimi* (Leiden: Apud Jordanum Luchtmans, 1696). I only had access to an incomplete copy in the Royal Cabinet of Coins and Medals, Leiden.

(Paris, 1696).

8. Business organization

As discussed in the introduction, it is hard to find conclusive evidence on an instrument maker's business organization. And if the Marburg documents do not inform us on the internal running of the workshop (did Johan have any assistants? we are not told), at least they give us glimpses of work put out to contract to other craftsmen.

In this context we may first look at the 1694 catalogue (see appendix). Its title specifies that the instruments listed were made by Musschenbroek, which implies that it did exclude items which he only bought and distributed. The following seems to corroborate this. In 1696, Musschenbroek sold prisms, which he said "are the best I could find, because they come from France and one cannot have them as perfect as before the war."[86] Prisms are not mentioned in the 1694 catalogue, although Musschenbroek had apparently already sold them before 1688, the outbreak of the War of the League of Augsburg to which he referred. The phrase 'which are being made by me' in the catalogue title may therefore be taken literally.

Glass-works

We have seen that the Musschenbroek workshop required glass strings to blow microscope lenses and glass tubes for the barometers (see section 6). Where did he have these made? There were glass-works in the Northern Netherlands in the seventeenth and eighteenth centuries, but it was an unstable branch of industry, in which very few production centres lasted long.[87] And even if there was a glass-blower in town, he might be incapable of supplying what one wanted. When Christiaan Huygens in The Hague worked on the improvement of Boyle's air-pump in 1661, he was unable to obtain specially blown glass receivers. He therefore took apothecary's jars and turned them upside down on a metal plate, thus creating the first bell-jar.[88] The next summer he could not have long tubes made in his hometown with which to recreate Boyle's latest experiments. To his

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[86] See n. 53.

[87] P.W. Klein, "Nederlandse glasmakerijen in de zeventiende en achttiende eeuw," *Economisch- en Sociaal-historisch jaarboek* 44, 1982, pp. 31-43. For the case histories of the individual glass-blowing centres this article rests mainly on F.W. Hudig, *Das Glas. Mit besonderer Berücksichtigung der Sammlung im Nederlandsch Museum voor Geschiedenis en Kunst in Amsterdam* (Wien, 1923).

[88] Alice Stroup, "Christiaan Huygens & the development of the air pump," *Janus* LXVIII, 1981, pp. 129-158, esp. pp. 131-132.

delight he found "une belle verrerie" in Bois-le-Duc in Brabant, which provided him with what he wanted.[89] Bernard Nieuwentijt, who engaged in experimental work in the 1690's in Purmerend, a small town in Northern Holland, also found it impossible to obtain receivers.[90]

From the Marburg correspondence we learn that Musschenbroek faced the same problem as his contemporary experimenters. For the bell-jars and receivers he sold with his air-pump he depended on glass-blowers outside the coastal province of Holland; we are not told where these were.[91] Replacing a broken copy was therefore a complicated affair. Dorstenius had to send the original brass mount back to Leiden, and Musschenbroek would forward this to the glass-blowers by the time he ordered a number of receivers for himself, "since the glass-blowers do not want to make one only."[92]

Considering Musschenbroek's skill in blowing the minute microscope lenses, one would imagine that he could also make other delicate glass instruments, such as hydrometers and thermometers. Yet, for glass puppets in a thermometer he apparently relied on some other specialist maker, but that man was abroad[93] and it eventually came to nothing. Such rare and partly conflicting glimpses remind us how difficult it is to unravel the secrets of a scientific instrument-making workshop.

Painters

In May 1695 Musschenbroek wrote that his magic lantern (see section 6) normally cost 50 guilders, together with ten wooden frames each filled with five glass slides. Apparently Dorstenius placed the order straight away, but it was not

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[89] Huygens's letters of 9 June, 6 July and 14 July, 1662, quoted in Hudig (n. 87), *Das Glas*, p. 64 and 69. At that period, Hendrick Heuck was active as a glass-blower in The Hague. The glass-blower who could provide what Huygens wanted was Willem van Bree. His factory was established in Bois-le-Duc in 1657 and was to remain in operation well into the eighteenth century (Hudig (n. 87), p. 114).

[90] R.H. Vermij, "Bernard Nieuwentijt als experimentator," *Tijdschrift voor de geschiedenis der geneeskunde, natuurwetenschappen, wiskunde en techniek* 10, 1987, pp. 81-89, esp. p. 82.

[91] Letter 28 July 1696: "Pour une campana de verre je n'avoit pas une presentement et on n'a pas en Hollande la commodité des verreries."

[92] Letter 26 October 1703: "Pour vostre garniture de verre je n'avoit presentement des verres qui s'accordez a vostre couvercle car l'ouvertures etoyent trop etroit. Mais quand Mons^{r} a occasion pour m'envoyer cette garniture je feraij un faire quand je fait faire pour moy mesme. Car les verrieres ne veulent pas faire pour un."

[93] Letter 13 March 1703: "Pour les petits homuncules des verres dans les termometres je n'ay presentement pas l'occasion d'en faire faire, mais je comprende bien vostre intention. Aussitot que le maitre qui fait ces choses revient dans nostre pays j'en feray faire." Sealed thermometers with immersed glass balls were made in Florence before 1660; W.E. Knowles Middleton, *A history of the thermometer and its use in meteorology* (Baltimore, Maryland: Johns Hopkins Press, 1966), p. 28.

dispatched until July 1696. The reason for the delay, as Musschenbroek explained in the accompanying letter, was that the slide painter had died, and as there was no one in Leiden who could complete the job, he had been forced to make a special trip to Amsterdam. More slides followed in the next years. The subjects of the paintings, Musschenbroek repeatedly assured in his letters, could be chosen by the patron. Once, however, he found he could not comply with Dorstenius' wishes. He had been unable to find an existing portrait of the crown prince of Hesse-Kassel to have it copied on glass, although "we have searched for it everywhere."[94] The amount of organization which went into these lantern slides makes it clear that jobs put out to contract to specialists outside the workshop were not necessarily a sinecure for Musschenbroek.

Clock-maker

Apart from the glass-blowers, other specialists too could be involved in the production of Musschenbroek's accessories for the air-pump. In 1703 he sent an "oval glass with the instrument of Cloese."[95] Evidently Musschenbroek turned to Bernard van der Cloesen, a clock-maker in The Hague, for the clockwork mechanism in this bell-in-vacuo, which to judge by the price (Hfl 15) was more sophisticated than the one sold to Dorstenius nine years earlier (see section 6).

Failure to deliver

It seems that on the whole Musschenbroek complied with Dorstenius' wishes, but there are some interesting exceptions.

Sometimes he could not find a specialist to make what his customer wanted. The thermometer with glass puppets inside, mentioned above, is one example. A comparable case was 'the little man in the barometer', which Musschenbroek had been unable to acquire for Dorstenius.[96] This gadget held the public imagination for several decades after it had first been sported by Otto von Guericke, who had surrounded it with an air of mystique hard to understand with hindsight. A wooden puppet floated on top of the mercury column, which Guericke held hidden from view, so that only this *virunculus* or *Wettermänchen*

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[94] Letter 12 December 1696: "Je vous envoyez avec cette presente les figures pour la lanterna magique. 17 pourtraits La prince aisné de Cassel n'avois [... illegible] pas eu son pourtrait car nous avons cherchez par tout. Encor 20 ordinaire selon vostre ordre."

[95] Letter 26 October 1703: "Je vous envoye un verre ovale garni au deux bouts de cuivre avec un couvercle, et aussi l'instrument pour la cloche dans le mesme verre." The invoice in that same letter specifies: "pour le verre ovale avec l'instrument de Cloese 6 Ryxdaalders."

[96] Letter 11 May 1695: "Le petit homme dans un barrometre nest je pas aqui on m'avoit promis de faire un mais ils nont pas fait et on na jamais fait. Combien que ce nest pas un grand art."

was visible, indicating the level with its tiny wooden forefinger as it inexplicably rose and sank.[97]

An instrument which Musschenbroek himself promised to make, but somehow never did, was a burning mirror. He wrote that he had polished these before, and would make one as soon as he had time, adding that he did not know of any specialist maker in Holland.[98] That may be true, but he almost certainly knew one in Germany: Ehrenfried Walter von Tschirnhaus, who at that time constructed huge burning lenses and mirrors. Tschirnhaus had studied in Leiden from 1669 to 1674, and had paid several visits to Holland since. He even had a commission-agent in Amsterdam for his burning devices,[99] and to send one from Leiden to Germany would therefore be carrying coals to Newcastle. Indeed, Dorstenius eventually acquired a burning mirror from Tschirnhaus[100] and probably had no reason to be dissatisfied with Musschenbroek's failure to comply with his wish here.

Finally we may look at an episode in which Musschenbroek more or less refused to act as retailer for another instrument maker, betraying something close to *jalousie de métier*. Apart from books, Van de Capelle (see section 7) had also owned instruments. These included a microscope with three lenses in a gilded leather case made by François Veeckens, an optical instrument maker in the vicinity of Leiden.[101] Evidently Dorstenius had instructed his Leiden supplier to bid for him, but Musschenbroek wrote that it had gone too high. If you want, he added, I can get you a new microscope by him, "but I assure you that you'll be disappointed, since you have one from me which is a hundred times

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[97] Fritz Krafft, *Otto von Guericke* (Darmstadt: Wissenschaftliche Buchgesellschaft, 1978), pp. 110-115. The weather puppet was discussed in Guericke's *Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio* (Amsterdam: van Waesberge, 1672), chapter 20 and illustrated in Plate 10, fig. 4. According to Krafft, a weather puppet was demonstrated before the Royal Society on 5 February 1673.

[98] Letter of 11 May 1695: "Touchant un miroir a bruler je na pas encore eu du temps pour faire car c'est un affaire qu'on ne fait pas ordinaire. Et je ne scay pas qu'il y a un homme en hollande qui fait cela pour son ordinaire, pour moy j'en a bien fait et je le feray bien mais il ne vaut pas la peine pour un. Je me resouviendray bien pour un faire pour Monsr."

[99] R.H. Vermij, "De Nederlandse vriendenkring van E.W. von Tschirnhaus," *Tijdschrift voor de geschiedenis der geneeskunde, natuurwetenschappen, wiskunde en techniek* 11, 1988, pp. 154-178.

[100] Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, p. 50.

[101] Auction catalogue (n. 85), p. 257, n°. 18: "Een Microscopium van Veeken met drie glasen in een verguldt lederen doosje." He may be identified with "François Veeckens, wonende een quartier uurs buyten Leyden, aen de Brug van Leyderdorp," who advertised in the *Amsterdamsche Courant* of 7 July 1697 that he made and sold a variety of optical instruments; see *Leidsch Jaarboekje* 1953, p. 113.

better."[102]

Conclusion

The two main characters discussed in this article were connected through the business of instruments. To judge by the amount of money involved, professor Dorstenius may well have been one of the major customers of the Musschenbroek workshop in the period around 1700. As his letters demonstrate, Musschenbroek's role was not restricted to the simple delivery of material goods: he acted virtually as a guide to his German patron. When Dorstenius turned to experimental science, no systematic courses had yet been published. In Leiden, Musschenbroek was intimately involved in the most progressive university of his time, and therefore far more versed in the new experimental science than his patron. He had to spell out most of the experiments to be conducted with the apparatus he sent; only occasionally he could refer to books, which he promptly sent along. Musschenbroek was thus in a position to take initiatives, which he did with proper business acumen: it is significant that Musschenbroek in some letters wrote that no new experiments were available.[103]

Musschenbroek was virtually Dorstenius' only supplier of instruments; Tschirnhaus' burning mirror (see section 8) and an unspecified set of mathematical instruments acquired in 1698 from Christian Schober in Leipzig are the only recorded exceptions.[104] The bulk of the instruments (for which see Table 2 in section 6) and all the books, for which Musschenbroek acted as a middleman for his brother-in-law, were bought in the period 1694-1696. Thus equipped, Dorstenius felt confident to offer for the academic year 1697 "a complete private course of experiments," thus introducing experimental physics to Marburg. If we look at it from the perspective of the eighteenth century, his apparatus was limited. Apart from the air-pump, which came with a range of accessories, there were only fifteen pieces or so which he may have used in his lecture demonstrations. The other instruments were for measurement (thermometer and barometer) or were used in other fields in which Dorstenius was active: the life sciences (microscopes), anatomy and surgery. Yet, the trade catalogue of 1694 and the

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[102] Letter 12 December 1696 (after discussing a magnet which he had not bought at the Van de Capelle auction, on which see n. 63): "pour cela ne nay achetez ny aussi la microscope de Veeken pour 3 dukatons puis on avoir un nouveau si Mons^{r} desire un je vous envoyerez bien un mais je vous asseure que vous sera trompe car vous avez un de moy qui est cent fois mieux."

[103] 13 March 1702: "Pour le present il n'y a rien de nouveau ..."; 30 November 1702: "Au reste il n'y a rien des nouveau des experiences ..."; 26 October 1703: "Il n'y a rien de nouveau de quelque machines."

[104] Hof (n. 5), *Die Entwicklung der Naturwissenschaften*, p. 50.

other documents make it clear that Dorstenius bought virtually everything his Leiden supplier was offering. And considering Musschenbroek's position in experimental science there is no reason to think that Dorstenius would have had a better set if he had turned to another specialist maker.

The Marburg documents are the most informative source yet found on the business aspects of the Musschenbroek workshop, and probably of any early scientific instrument-making workshop. Its repertoire during the period 1694 to 1703 is revealed in considerable detail. Johan van Musschenbroek emerges as a pioneer in marketing techniques: he was the first instrument maker to issue a priced trade catalogue. He was alert on extending his repertoire, displaying a good sense of what the market was ripe for. Thus, he launched a low-budget air-pump, of which he seems to have been rather proud. When sitting to a painter he chose to be represented with it, and not – as his sons were to do later – with the workshop's most impressive instrument, the large and ornate diagonal air-pump.[105] We also learn something about the way Musschenbroek organized his business. Thus, he put out work to contract to glass-works outside Holland, to unnamed painters in Leiden and Amsterdam and to the clock-maker Bernhard van der Cloesen in The Hague.

Dorstenius paid some Hfl 700 to Musschenbroek for his instruments. Even if we subtract the money spent on items unrelated to his physics teaching, such as the anatomical and surgical instruments, the invested sum remains impressive. Heilbron, comparing the expenditure on required apparatus to professorial incomes, estimates that the cost of a full set of instruments in the 1730's was about equal to the annual income of a well-paid professor of physics.[106] It is obvious that for Dorstenius too the instruments were a considerable investment, the more so as he was emphatically not a well-paid professor. In fact, for assuming the extra burden of teaching physics he was only granted a disappointingly low rise of salary of 40 German guilders (roughly equivalent to 50 Dutch guilders[107]), and even these he only began to receive well after acquiring the bulk of his instruments. The conclusion must be that Dorstenius' prime motive for acquiring his instruments was his own enthusiasm, rather than a realistic expectation for a return from salary rise. Or did he make money on the side by giving private lectures with his 'costly machines' from Holland?

Finally, what became of the Musschenbroek instruments in Marburg?[108]

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[105] The large diagonal pump was chosen, with a set of Magdeburg hemispheres suspended from a tripod, as requisite for the double-portrait of Jan and Petrus van Musschenbroek, painted in 1715 by Hieronymus van der Mij, which is in the Museum Boerhaave.

[106] Heilbron (n. 21), *Elements of early physics*, p. 146.

[107] Private communication from Arent Pol, Royal Cabinet of Coins and Medals, Leiden.

[108] This last paragraph is based on Schmitz (n. 5), *Die physikalische Gerätesammlung*.

After Dorstenius' death in 1706, his family sold them – together with his library – to the professor of medicine Jean Borel (1684-1747). With this 'dowry', Borel managed to secure the physics chair in 1715. Some of Musschenbroek's manuscripts bear references to the corresponding pages in Valentini's *Rüst- und Zeughaus der Natur* published in 1714 (see Figs. 8 and 9). These were probably jotted down by Borel or by a later professor and indicate that Musschenbroek's instructions continued to be consulted by later users of the instruments. Eventually the collection, together with later additions, was acquired by the university in 1762 for 350 Reichstaler. It is obvious that by then the old instruments from Holland had lost their splendour. Five years later the university board heard severe complaints about the poor state of the air-pump, the Magdeburg hemispheres and the microscopes. In 1785, the air-pump was replaced and scrapped. The other apparatus faded away unrecorded. A search through the antique instruments in the Physikalisches Institut in Marburg has revealed no trace of the scientific instruments which had arrived there almost three centuries earlier from Leiden.[109]

[109] This was kindly reported to me by Prof.dr. W. Walcher in his letters dated 30 September and 20 October 1988.

Summary

Between 1694 and 1703, the Leiden instrument maker Johan Joosten van Musschenbroek sold some sixty physical, optical, anatomical and medical instruments to professor Johann Daniel Dorstenius at Marburg University, Germany. Dorstenius bought these on his own initiative and out of his own pocket. With his lectures he introduced experimental physics to Marburg.

The instruments themselves have been lost, but the documents received by Dorstenius survive. This article serves to present and discuss these previously unpublished documents, which include letters, invoices, instructions for use and the earliest instrument-makers' trade catalogue. These documents contain unique information on the repertoire and the business organization of the Musschenbroek workshop with its close connections with the progressive University of Leiden.

Museum Boerhaave
Postbox 11280
2301 EG Leiden
The Netherlands

Appendix

The hand-written catalogue of the Musschenbroek workshop transcribed below dates from spring 1694. As discussed in section 5, this is the earliest known priced trade catalogue of any scientific instrument-making workshop. The prices are in Dutch guilders and stuivers, which relate as 1:20. (I have omitted a further subdivision given in the price, as these were all entered as '0' and hence are meaningless). The numbering is not on the original document. For a partial translation/explanation the reader may turn to section 6, Table 2. The implications of the title are discussed in section 8.

Catalogus van alle d'instrumenten die by my gemaakt werden

1	De groote soort van lugtpompen met haar glasen, pypen, copere bollen, fontein, kranen, marmere cilinders, houte machine en verdere toebehooren komt	500-0
2	die van dese nevensgaande figuur	175-0
3	een glas met instru[ment] om de valvula plantarum te toonen	14-0
4	2 glasen en 1 tubus om de resperatio te demonstreren	4-10
5	kopere cubus van 1 half voet	15-15
6	kop[eren] cilinder	50-0
7	ae[oli]pila	4-0
8	een anatomie speut, 8 tubi 1 sleutel	16-10
9	een dubbelde kraan met 2 flexile tubi tot de speut	7-10
10	6 tubi tot de transfug[ionem] sangui[nis]	2-2
11	blaas tubi stuk	0-15
12	stylos van koper loot, of walvisbeen	0-2
13	smoul schroever	4-0
14	drilbankie, 6 drillen, 2 baleyne boogen om gaaties in de beenen te booren om een scheletium	7-10
15	de groote soort van microscopia met 6 gla[sen]	18-18
16	de kleinder soort	15-15
17	de slegte soort met 3 glasen	9-9
18	flexile silvere cateter	5-0
19	een ordinaire silvere mans cateter	5-0
20	een vrouwe cateter	3-10
21	een clisteer speut met een lange flexile canaal om sig selfs te konnen klisteren na d[']inventie van Doct[r] de Graaf	10-0
22	een instru[ment] om met rook van tabak te clisteren	1-10
23	een met de blàas te klisteren	0-12

24 banden van yser voor een hernia de toevouwende	9-9
25 een ordinaire met een schroef	9-9
26 een minder soort	7-10
27 bandt voor die gesneden syn en lek syn door de wont of penis	12-12

breukbanden en harnassen voor de bultagtige lighamen is myn principal metier maak nog oneyndig veel andere saaken die dagelykx voorkomen

mijn heer de Volder heeft een instrument om de wetten van de beweegingh te toonen dat heel fray is kost ontrent 60 guld[en]