Newton and the Netherlands

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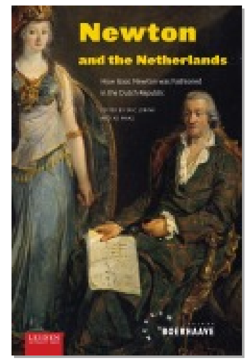

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‘The Wisest Man to Whom this Earth Has as Yet Given Birth’

Petrus van Musschenbroek and the limits of Newtonian natural philosophy

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Petrus van Musschenbroek (1692–1761) is often bracketed together with Willem Jacob ’s Gravesande (1688–1742) as the two great Dutch popularizers of the natural philosophy of Isaac Newton. Although each of them had his own individual approach, both men were experimental physicists who followed and defended Newton’s scientific method. They disseminated this approach in their teaching, which they improved drastically, in particular thanks to the often newly designed demonstration instruments.[1] A considerable number of students all over Europe learnt the first principles of physics from their textbooks or by attending their lectures.[2] Also in their academic orations both physicists often discussed Newton’s empirico-mathematical method and emphasised the reliability of its results. In the dissemination on the European Continent of Newton’s ideas, method and discoveries by means of teaching, textbooks and orations lies the enduring merit of both Dutch physicists.

However, Van Musschenbroek did more than just spread the word of this British genius. He also conducted research, in which he was guided by Newton’s methodology. In practice, Van Musschenbroek’s focus, however, was aimed particularly at the empirical aspect. This article, by focusing on the principles of research of Van Musschenbroek, aims to reveal some dilemmas raised by the limits of this empiricism. It could lead, as will be shown, to unfruitful observations and sometimes even to pointless speculations. This article will start with a survey of Van Musschenbroek’s life and career and the most important part of his scientific legacy: his textbook oeuvre. This will be followed by a discussion of Van Musschenbroek's methods of research: first his empirical studies and then his views on matter and forces.

Petrus Van Musschenbroek: Life and career

In 1726, when the third edition of Newton's *Principia* appeared, Petrus van Musschenbroek, at the time a 34–year-old professor of philosophy, mathematics and astronomy at the University of Utrecht, published a concise textbook entitled *Epitome elementorum physico-mathematicorum*. In the preface he mentions a number of luminaries in the rapidly expanding natural sciences. Newton is one of them, though Van Musschenbroek seems to believe that he surpasses them all. Newton is the only scientist who Van Musschenbroek praised in such transcendent terms as 'a man of extraordinary talent and divine acuteness in physics and mathematics'.[3] Such extravagant appreciation of the author of the *Principia* and the *Opticks* was, at that time, certainly not common on the European Continent.

Petrus (Pieter) van Musschenbroek was born in 1692 as the second son of the instrument maker Johan Joosten van Musschenbroek (1660–1707) and Margaretha van der Straeten (1659–1743). The Van Musschenbroeks were the most well-known family of instrument makers in the Dutch Republic in the period 1650–1750. In particular, Petrus' elder brother Jan gave the business a great reputation by producing air-pumps and other equipment for use in physical experiments. A unique collaboration existed between Jan van Musschenbroek (1687–1748) and the Leiden professor Willem Jacob 's Gravesande in the production of instruments for the demonstrations that enlivened the latter's lectures on experimental physics.[4] Contrary to his brother, Petrus chose an academic career. He studied medicine under Herman Boerhaave (1668–1738) in Leiden, and in 1715 he gained his doctorate under the renowned physician with a dissertation about air in bodily fluids.[5] His strongly empirical attitude was already apparent in this work.

The University of Leiden was surely the place where Van Musschenbroek became (better) acquainted with the ideas of Newton and other English investigators. A pirated edition of the second edition of the *Principia* (1713) produced in 1714 enabled many to become acquainted with Newton's main work.[6] In 1715 Boerhaave was one of the first who openly expressed his high esteem for Newton in an academic address (see Knoeff in this volume). All his life Van Musschenbroek was a faithful follower of Boerhaave.

In 1717, the same year that 's Gravesande became a professor at Leiden, Van Musschenbroek made a study trip to London, where he attended the lessons in experimental physics given by John Theophile Desaguliers (1683–1744), with whom he remained on friendly terms. He must have met other members of the Royal Society, but little is known about these contacts. We do know, from a letter dating from 1726 to which I will come back, that he had personally met with Newton. He only became a member of the Royal Society in 1734.

After his return from England Van Musschenbroek briefly attended 's Gravesande's lectures. In 1719 he was offered a professorship in mathematics and philosophy at Duisburg by King Wilhelm I of Prussia. On this occasion he was granted a doctorate *honoris causa* in philosophy. The degree certificate features the signatures of 's Gravesande and Wolferd Senguerd (1646–1724), who was also a member of the philosophical faculty of Leiden University. No work written by Van Musschenbroek appeared in print during the Duisburg period (1719–1723). Nothing is known about an inaugural lecture either. We do know, however, that after only six months he established an *'observatorium astronomicum'* on top of the Salvatorkirche. In the second year he was also appointed professor of medicine. He assumed this new function with a lecture on the possibility of linking medicine with natural philosophy.[7]

In 1723, at the age of 31, Van Musschenbroek became professor of philosophy and mathematics in Utrecht, where he introduced Newtonian natural philosophy. A professorship in astronomy was added in 1732, after the observatory on the Smeetoren (Smee Tower) had been very much improved. Van Musschenbroek assumed his duties in 1723 with an *Oratio de certa methodo philosophiae experimentalis*, in which he pleaded for Newton's empirico-mathematical method. A number of scientists were discussed, but Newton was the 'greatest of all mortals' or even an 'immortal light'. These were very novel views in Utrecht.[8] Late in the year 1739, Van Musschenbroek went back to Leiden. Formally he took over the chair of Jacobus Wittichius (1677–1739), but in practice he was known as successor to 's Gravesande (who died in 1742) as the figurehead of Leiden natural philosophy. Van Musschenbroek would stay in Leiden until his death in 1761.

The *Epitome*, a survey of the principles of physics mentioned above, was based on the physics lectures he delivered during the first three years of his Utrecht professorship. It seems he wanted Newton to know that he contributed to the dissemination of his theories, for he sent a

Fig. 1: Jan (standing) and Petrus van Musschenbroek, by Hieronimus van der Mij (1715). (Museum Boerhaave, Leiden, P00810)

copy to London, where the then 83–year old author of the *Principia* had been Master of the Mint for many years. Just like 's Gravesande, Van Musschenbroek displayed an almost diffident veneration for him:

> Being an admirer of your wisdom and philosophical teaching, of which I had experience while in Britain in familiar conversation with yourself, I thought it no error to follow in your footsteps (though far behind), in embracing and propagating the Newtonian philosophy. I began to do so in two universities, where the triflings of Cartesianism flourished, and met with success, so that there is hope that the Newtonian philosophy will be seen as true in the greater part of Holland, with praise of yourself. It would flourish even more but for the resistance of certain prejudiced and casuistical theologians.

> I have prepared a compendium for beginners with which, if it does not displease you greatly, I shall be well satisfied. I shall always endeavour to serve the wisest man to whom this Earth has as yet given birth. (Utrecht 23 February 1726)[9]

Quotations such as this one — to which several others could be added — might suggest that Van Musschenbroek was a slavish follower of Newton. Such a conclusion, however, would be premature. Just like 's Gravesande, Van Musschenbroek chose Leibniz's position in the so-called *vis viva* controversy — whether the 'force' of a moving body is proportional to mv (René Descartes, 1596–1650) or to mv^2 (Gottfried Leibniz, 1646–1716) — while most English Newtonians opted for Descartes' view.

Textbooks

Van Musschenbroek's textbooks are undoubtedly the most important part of his scientific legacy. The *Epitome* was the first of these. All subsequent publications can be viewed as adaptations and extensions of this book, even when the titles were different. In 1734 and 1741 the first and second editions appeared of the *Elementa physicae conscripta in usus academicos*, which was followed in 1748 by *Institutiones physicae conscripta in usus academicos*; and finally in 1762 Johan Lulofs (1711–1768) published posthumously a textbook that had been expanded and brought up to date by Van Musschenbroek himself, under the title *Introductio ad philosophiam naturalem*. In the same year an abridged version was made available for students, the *Compendium physicae experimentalis conscripta in usus academicos*, comparable in size to the *Epitome*. In addition, Van Musschenbroek published in 1736 the *Beginselen der natuurkunde, beschreven ten dienste der landgenooten*, the first modern physics textbook in Dutch, of which a new edition appeared only three years later (the first word of the title having been changed from 'Beginselen' to 'Beginsels'). This work closely resembled the Latin textbooks. In several European countries reprints appeared of the Latin textbooks, in particular of the *Elementa physicae* of 1741. There were also translations into French, German, English and Swedish. Contrary to present-day practice, these textbooks also contained the results of his own experiments.[10]

In line with his preference for empirical research (see the next section), Van Musschenbroek's textbooks are less mathematical in approach than the various editions of 's Gravesande's textbook. Petrus Camper (1722–1789), who gained his doctorate under Van Musschenbroek, advised new physics students to use the textbooks of his teacher because they contained less mathematics. Van Musschenbroek informed his readers extensively about the results of his experiments, even though he wasn't sure what to do with them. 's Gravesande usually included his measurements only if they could be processed mathematically and led to clear conclusions. In their academic addresses these different attitudes to mathematics were equally apparent: 's Gravesande paid special attention in one of his academic orations to the benefits of mathematics, while Van Musschenbroek gave an address on the proper experimental method.[11]

The content of 's Gravesande's *Physices elementa mathematica* has a stronger focus on Newton's work than Van Musschenbroek's textbooks. This is already apparent in the subtitle of 's Gravesande's work: *Introductio ad philosophiam Newtonianam*, which is lacking in the titles of Van Musschenbroek's textbooks. In this respect a comparison of the third edition of 's Gravesande's textbook (1742) with the second edition of Van Musschenbroek's *Elementa physicae* (1741), which appeared more or less simultaneously, is illuminating. The two physicists are entirely guided by Newton in the areas of gravitation, attractive forces, (celestial) mechanics, optics and the like, but Van Musschenbroek also pays attention to magnetism, electricity, heat, meteorology and the strength of materials, topics that are largely ignored by Newton and 's Gravesande. On the other hand, 's Gravesande discusses the Newtonian world system, which is not included in his textbooks by Van Musschenbroek. In the wake of Robert Boyle (1627–1691), Newton and Boerhaave, Van Musschenbroek pays attention to chemistry, which is ignored by 's Gravesande.

The limits of empiricism

Following a 'Newtonian' line of reasoning, Van Musschenbroek contended that reliable natural science can only be based on observation and experiment. From the evidence that has been obtained empirically, conclusions have to be drawn with the help of logic and mathematics and, if possible, laws have to be formulated that in their turn can be tested experimentally, so as to discover the causes of phenomena. In Van Musschenbroek's words:

> If a natural science is to be established and advanced, it will either be based on sensory perception and subsequently mathematical reasoning, or it will never come into being.[12]

and also:

> The Newtonians collect observations, and perform experiments, which they compare with each other, and from which they draw conclusions, which they again confirm with experiments, thus reasoning from facts, and attempting to discover the causes of phenomena from them.[13]

To be able to draw reliable conclusions and to give them a mathematical form, sufficiently reliable and varied factual evidence has to be available. This is strongly emphasized by Van Musschenbroek. In his *Introductio ad philosophiam naturalem* (1761) he writes: 'for only the observations, only the experiments constitute the true and solid foundations of natural philosophy'.[14] This emphasis on collecting evidence in itself was not introduced by Newton, but is characteristic of the Baconian tradition in natural philosophy. Around 1600 Francis Bacon (1561–1626) argued for the need of a 'natural history', a 'data bank' of reliable empirical evidence so as to construct a new natural science from the foundations.[15] Bacon's empiricism is a rational empiricism: the evidence that was collected would have to be ordered and processed by reason. In 1715 he was still mentioned in adulatory terms by Boerhaave.

There is also a certain element of Baconianism in Van Musschenbroek. Time and again we find in his publications lists, sometimes long lists, in which experimental results are assembled. In the *Introductio* there is a list of specific gravities that occupies no fewer than 26 pages. In his work we come across lists of substances that are attracted by magnets, lists of heights of fluid rise in capillaries, etc. His extensive meteorological investigations also reflect the Baconian tradition.[16] And yet, characterizing Van Musschenbroek purely as a Baconian doesn't do justice to his intentions. Just like his teacher and colleague 's Gravesande, he reiterated the need for processing the acquired evidence mathematically, if this was possible. In physics, empirical observation and mathematics cannot be separated, he argued. However, in fact he often published lists with a multiplicity of experimental results, which in future might be useful for the intended purpose, rather than jumping to conclusions and formulating mathematical relations on the basis of a few superficial observations.[17] At the same time he strongly emphasized the importance of finding forces and the laws they obey, an eminently Newtonian theme. Many of his investigations were devoted to such attempts in the areas of magnetism, capillarity, the strength of materials, and heat (expansion).

His unwillingness to make hasty generalizations is closely linked with the stringent demands he made on empirical research so as to produce reliable results. In an *éloge* devoted to Van Musschenbroek, Nicolas de Condorcet (1743–1794) drew attention to this point:

> One finds in his works a long series of well-performed experiments, the results of which have been exactly calculated; a large number of well-observed and precisely described facts, several experimental devices, either invented or improved by him, and above all an excellent method of philosophizing. When his investigations do not lead to general results, he contents himself with presenting his experiments baldly, and he rather runs the risk of being considered a physicist without vision, than producing systems instead of truths.[18]

A good example of Van Musschenbroek's empirical research are his studies on magnetism. In contrast to 's Gravesande, who only referred to it in passing, Van Musschenbroek occupied himself extensively with it. He published his study of this topic in *Dissertatio physica experimentalis de magnete*, as a part of a collection of treatises, which appeared in 1729. It was later reprinted separately in Vienna (1754).[19] In 1734 Emanuel Swedenborg (1688–1772) included large parts of the text in his *Examen principiorum rerum naturalium cum phaenomenis magneticis* (1734).[20] Van Musschenbroek's interest in magnetic phenomena is in part connected with its importance for navigation. Part of his work concerns this application. The Baconian element is abundantly present: there are many lists and tables in the book with observational data and results of measurement. He formulated the main purpose of the study of magnetism into two questions, viz. what link is there between the force and the distance of two attractive or repulsive magnets, and what is the essence, the true cause, of the phenomenon of magnetism?

Much earlier, in 1712, at the request of Newton, who had been president of the Royal Society since 1703, Francis Hauksbee (1660–1713) and Brook Taylor (1685–1731) had attempted to find a force law for magnetism by means of the deflection method: a magnetic needle placed in the meridian was deflected over a certain angle under the influence of a nearby magnet. By measuring the angle of deflection while the magnet was placed at different distances and calculating the force as a function of this angle, they tried to find a force law of the form $F \propto r^{-n}$, the exponent n to be derived from observations. They did not, however, manage to produce a satisfactory result. What is measured by this method, incidentally, is in fact the couple that makes the needle turn, and not the total magnetic force. Nevertheless, in the second edition of the *Principia* (1713), that is, after the experiments by Hauksbee and Taylor, Newton stated that a few rough measurements showed that the exponent n approximately equalled 3.[21]

Van Musschenbroek began his investigations in 1724.[22] He didn't use the deflection method but employed a balance. The force between a magnet suspended from one arm of the balance and a magnet attached to the table underneath was measured by placing a weight in the scale attached to the other arm that counterbalanced the force of the magnet. In his treatise of 1729 he published many observations, but was unable to derive a law. Van Musschenbroek continued his experiments for many years as is apparent from the repeatedly revised section on magnetism in his textbooks.

More than ten years later he formulated several laws of the form $F \propto r^{-n}$ for specific shapes of magnets or iron bodies and for a limited distance interval. They first appeared in a manuscript entitled *De viribus magneticis* (1740). There were four, where $n = 1$, $n = 1.5$, $n = 2.5$, and $n = 4$. As from the second edition of the *Elementa physicae* (1741) they were also included in the textbooks. The last case was already present in the second edition (1739) of the *Beginselen*. The notion of 'distance' (for example, between two globes) was now made more precise by taking the volume of the space between two bodies within an enveloping cylinder or cone, which involves a correction of the shortest distance. It should be pointed out that several contemporaries of the Dutch physicist concluded that there were general laws purely on the basis of a small number of observations. Van Musschenbroek never did that. His respect for the experimental results was too great for that.

In the 1740 manuscript he expressed already his disappointment about his experimental results:

> I am not entirely convinced that one and the same law applies to all magnets on earth, as I have used only three magnets in the investigation to be described below. However, if other magnets were to obey different laws, the investigators of nature would never see their wish [for a universally valid force law] fulfilled and would do better to give up their investigations and stop wasting their time.[23]

Drawing conclusions was hampered by the use of weak, often not very homogeneous natural magnets, and by the fact that there are two attractive and two repulsive forces if the magnetism is located in two points in a magnet. Apart from these problems, it is clear that the Baconian-heuristic method fails in this case. This approach implied that Van Musschenbroek was looking for a force law between two bodies as they are given in the experimental arrangement. In 1819, the Norwegian (geo) physicist Christopher Hansteen (1784–1873) pointed out that experiments like Van Musschenbroek's were not suited to finding a general law for magnetism, because the results also depended on the intensity distribution of the magnetism of the bodies that were used, while without a theory the concept of 'distance' was also problematic.[24]

Although Van Musschenbroek recognized these problems himself, he kept reiterating that an empirical approach was required: the magnet had to be subjected to a variety of experiments, without involving any hypotheses. It only became possible to find a law when Charles-Augustin de Coulomb (1736–1806) managed, with the help of a torsion balance, to measure the force between two point-poles. However, the inverse square law was only definitively accepted as the general law for the magnetic force when it was possible to perform experiments the results of which corresponded with the calculations made on the basis of the theory.[25]

Matter and forces

Van Musschenbroek was extremely negative about Descartes. In many places he denounced the dreaming up of general causes in order to construct a natural science deductively, without consulting nature itself. Cartesians know no better than piling hypothesis upon hypothesis, he said, so that natural science is debased to a 'science of guessing'. More than once he poured out the vials of his displeasure over the natural philosophers who in their studies devised chimaeras and 'inanities'. It is better to devote one's time to collecting observations than to building specious systems on an unsound foundation of imaginary principles.[26] In 's Gravesande's work this polemic is almost completely lacking, even though he was as disposed to hypotheses as Van Musschenbroek was. Only in the preface of his *Physices elementa mathematica* does he explicitly reject hypotheses.[27]

However, notwithstanding his warnings against using 'unsound imaginary principles', Van Musschenbroek himself could not prevent slipping into speculations about matter and forces, for instance in the discussion about the problem of the divisibility of matter. Van Musschenbroek addressed this issue following the British Newtonians and 's Gravesande. Contrary to 's Gravesande who viewed divisibility as a mathematical question, Van Musschenbroek distinguished between 'mathematical divisibility' and 'actual divisibility'. From the fact that the space taken up by a body can be shown to be infinitely divisible mathematically it cannot be concluded that the body itself is infinitely divisible. For that we have to rely on experiment. On the basis of arguments derived from experience, he was convinced of the existence of indivisible particles. Like Newton in the 'Queries' of the *Opticks*, he assumed that God had created these atoms in the beginning. He admitted that firm proofs were lacking, and he didn't want to impose this view upon others as an established fact.

The Newtonian John Keill (1671–1721) disputed the distinction between 'mathematical' and 'physical divisibility'. The divisibility of a physical body depends essentially only on its extension, a viewpoint that Descartes had adopted as a necessary consequence of his identification of matter and extension. Atoms created by God that are indivisible by the forces of nature cannot exist in Keill's view, as God is capable of dividing them. 's Gravesande shared this view, although he did not engage in a polemic against the atomists.[28]

Concerning the constitution of physical bodies Van Musschenbroek followed Newton. Atoms are the ultimate building blocks of all bodies. A small number of atoms forms a first-order particle; a number of these particles forms a second-order particle, and so on. Large bodies are composed of such agglomerates of different orders. Only homogeneous bodies are made up of particles of the same order. The real quantity of matter of a body remains unknown to us, as we don't know what the volume of the pores is. On the assumption that each particle of order n consists half of particles of order $n-1$ and half of empty space, the ratio of solid mass to empty space in a particle of order n equals $(2n-1) : 1$. Van Musschenbroek derived this calculation from Newton's *Opticks*.[29]

An important aspect of the Newtonian explanation of nature is the use of attractive and repulsive forces. In the *Principia* Newton had not only explained the motion of the planets with the help of the principle of general gravitation, which was highly praised by his followers, but he had also hinted at other attractive forces, stronger than gravitation and only active at short distances. In addition we also come across repulsive forces. In the preface of the *Principia* Newton had already expressed the conjecture: 'that all phenomena may depend on certain forces by which the particles of bodies, by causes not yet known, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede'.[30] Newton had given a hypothetical explanation of Boyle's law (pv = constant) by assuming a repulsive force between the particles of an elastic fluid, which was only active between adjacent particles and that was inversely proportional to the distance between them. And conversely he derived Boyle's law from this force.[31]

The success of Newton's theory of gravitation led to attempts by many investigators to discover the effects of forces in natural phenomena. In Van Musschenbroek's work forces play an important role, perhaps even more than in the work of other Newtonians in and before his time. In his textbooks he extensively discussed magnetism, electricity, capillarity and cohesion in solid bodies (strength of materials), while his most important scientific treatises (1729) were devoted to these phenomena.[32]

Van Musschenbroek usually assembles these natural phenomena, together with gravitation, under the heading of attractive (or repulsive) forces. By 'attraction' in the strict sense, however, he denotes the force that makes the smallest particles of bodies approach each other and adhere to each other. Gravity and this specific attraction are both invariable properties of matter, which God has implanted in physical bodies. That these are indeed two different forces is apparent from observation. The attraction between small particles is much stronger than the force of gravitation and diminishes so quickly that it is active only over very short distances while gravitation works over 'infinitely far distances'. Following Newton and the other Newtonians, he claims that a force law $F \propto r^{-n}$, where $n > 2$, must apply to this phenomenon.[33]

The examples that Van Musschenbroek adduces as proof for the existence of attraction are also to be found in Newton, Boerhaave, 's Gravesande and the English Newtonians. Amongst them are capillarity and cohesion in solid bodies, which he had investigated much more extensively than they had done. He calls cohesion between particles in solid bodies *cohaerentia*, or the 'strength, firmness or resistance of solid bodies'. He not only paid attention to this topic in his textbooks, in particularly in his *Introductio*, but with an eye to practical applications he had already in 1729 published an extensive study of the strength of wood, metal and other materials, which was one of the treatises I mentioned above.[34] From the large number of measurements he had derived a few formulae, one of them concerns a 'snap formula' for the force needed to break a vertical beam.[35]

Like Newton, Boerhaave and John Freind (1675–1728), Van Musschenbroek explains chemical action by attractive forces. If in a material that is made up of substances A and B the particles of a third substance C attract those of A more strongly, the C particles will oust the B particles. Precipitation reactions as well as dissolving of metals in acids have to be explained in this way. In addition, the shapes of the particles play a role in these processes. The sharper the particles of the acid in which a metal dissolves, the more easily these particles will 'cut' the metal particles to pieces.[36] These kind of speculative ideas were held not only by the adherents of Newton, but also by those of Descartes and Pierre Gassendi (1592–1655), for whom all phenomena had to be explained strictly mechanically, that is, exclusively on the basis of the shapes, sizes and arrangement of particles, and without what they viewed as 'occult' things like forces. Boerhaave also gives explanations that combine the action of forces with the shapes of the particles of a dissolving fluid. The better the particles of the one substance fit into the pores of those of the other, the more easily the mixture (solution) comes into being.

Both Van Musschenbroek's and Boerhaave's attitude is rather ambiguous from an empiricist point of view. On the one hand they warn against transgressing the bounds imposed by observation by introducing unverifiable hypotheses, but on the other hand they easily speak of sharp acid particles and globular water particles, although they certainly make no absolute statements about these shapes.

Because of the importance of gravitation the followers of Newton initially paid more attention to attraction than to repulsion. Only in

Fig. 2: Pyrometer, an instrument invented by Van Musschenbroek to measure the rate of expansion of metal rods with the temperature. (Museum Boerhaave, Leiden, V09550)

the second half of the eighteenth century did repulsion and attraction become equivalent principles (magnetism, electricity). Van Musschenbroek discusses repulsion in his textbooks starting in 1748. In his *Introductio* he writes about the two forces:

> The attractive force is thus active at a distance from the bodies; its action is stronger in a smaller interval and weaker in a larger interval, strongest when there is direct contact, but its influence only extends over a short distance. [...] [W]here the attractive force leaves off, a repulsive force begins.[37]

Heating, fermenting and putrefaction of materials can produce vapours which, like air, consist of mutually repulsive particles. Following Newton and 's Gravesande, Van Musschenbroek derives from Boyle's law that this repulsive force is inversely proportional to the distance between the particles. He adds the comment that Boyle's law is not generally valid, as is shown by experiments. When a gas is compressed very strongly the law no longer applies as the particles will in the end touch one another.[38]

Optical phenomena like refraction, reflection and dispersion are also explained by Van Musschenbroek, following Newton and 's Gravesande, by attraction and repulsion. 's Gravesande does not assume that light is material, but he does see an analogy between the interaction of particles and the interaction between matter and light. Refraction is, according to Van Musschenbroek, the effect of attractive forces of the body on which the light falls and is refracted. Reflection is caused by repulsive forces acting outside the attractive sphere of the body. Newton himself explained the problem of why some light rays are refracted while others are reflected with his celebrated 'fits of easy transmission' and 'fits of easy reflexion'. Van Musschenbroek admitted he had no answer to this question. Like 's Gravesande he left Newton's 'fits' untouched.[39]

Conclusion

Despite all the efforts he put into gaining new insights in the workings of nature by his experiments, Van Musschenbroek (like 's Gravesande) became widely known mainly through his teaching and his textbooks. To be sure, he also lives on as the inventor of the pyrometer and the famous Leiden jar,[40] but Van Musschenbroek's contributions to the development of physics were limited and were forgotten rather soon. Time and again Van Musschenbroek propagated research according to 'Newtonian' principles. However, his reluctance to make 'premature' generalizations resulted in a strong bias on observations, which gave his studies a marked Baconian flavour.

Strictly Newtonian or not, Van Musschenbroek's research revealingly shows the limits of eighteenth-century empiricism. The seemingly endless accumulation of observations did not lead to natural laws concerning the behaviour of the weather or a force law for magnetism. Interestingly, Van Musschenbroek himself realized and admitted his failure in this respect. On the other hand, despite his professed aversion to 'hypotheses', Van Musschenbroek engaged in speculative (and fruitless) ideas about matter, forces and chemical reactions, which were hardly founded upon empirical evidence or mathematical proofs – the two pillars of Newton's methodology. The self-proclaimed Newtonian, Van Musschenbroek proved able only to a limited extent to bring into practice the kind of science that he disseminated in such a successful manner.

Notes

I would like to thank Bas Jongeling for correcting my English.

1 See the collection of devices designed and used by 's Gravesande and Van Musschenbroek in the Boerhaave Museum, Leiden.

2 An example is the French refugee, Jean-François de Boissy (1704–1754), who in 1746 – four years after the death of 's Gravesande – wrote to his brother that he attended Van Musschenbroek's physics lectures because they were fun, while he followed other courses only because they were obligatory. C.E. Engel, *Jean-François de Boissy (1704–1754), un réfugié français du XVIIIe siècle d'après sa correspondance* (Neuchâtel 1941), pp. 52–53: *'La physique sous M. Muschenbroek [sic], le premier homme du monde pour les expériences. C'est le seul collège qui me faisse plaisir; aux autres, je vais par devoir.'*

3 P. van Musschenbroek, *Epitome elementorum physico-mathematicorum, conscripta in usus academicos* (Leiden 1726), Praefatio.

4 P. de Clercq, *At the sign of the oriental lamp: the Musschenbroek workshop in Leiden, 1660–1750* (Rotterdam 1997), esp. 36–50, 73–102 and 134–149.

5 P. van Musschenbroek, *Disputatio medica inauguralis de aëris praesentia in humoribus animalibus, quam ... pro gradu doctoratus summisque in medicina honoribus ... ad diem 12. novembris 1715 ...* (Leiden 1715).

6 I. Newton, *Philosophiae naturalis principia mathematica* (London 1687); second edition (Cambridge 1713); pirated edition (Amsterdam 1714, 1723); third edition (London 1726), translated by I.B. Cohen and A. Whitman (eds), *The Principia: mathematical principles of natural philosophy with* 'A guide to Newton's *Principia*' by I.B. Cohen (Berkeley, Los Angeles 1999).

7 F.A. Meyer, 'Petrus van Musschenbroek: werden und Werk und seine Beziehungen zu Daniel Gabriel Fahrenheit', *Duisburger Forschungen* (1961), pp. 1–51, on 3–9; W. Ring, *Geschichte der Universität Duisburg* (Duisburg 1920), p. 187; C. de Pater, *Petrus van Musschenbroek (1692–1761), een Newtoniaans natuuronderzoeker* (PhD-thesis, Utrecht 1979), pp. 26 and 99 (fig. 9).

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10 For an extensive bibliography, see: De Pater, *Musschenbroek* (note 7), pp. 349–371.

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13 P. van Musschenbroek, *Beginsels der natuurkunde, beschreeven ten dienste*

der landgenooten (Leiden 1739), p. 105; cf. De Pater, *Musschenbroek* (note 7), pp. 57–121.

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32 Cf. Van Musschenbroek, *Physicae experimentales* (note 18); see also Van Musschenbroek, *Tentamina* (note 25), pars 2, pp. 12–57 ('Addidamentum' about the pyrometer).

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