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THE WEATHERGLASS AND ITS OBSERVERS IN THE EARLY SEVENTEENTH CENTURY

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Introduction: the inverted-glass experiment

Air expands when heated and contracts again when it cools down. This phenomenon plays a very important role in determining weather and climate, because it is the sun's heating power which sets in motion the air masses of the Earth's atmosphere.[1] The thermal expansion and contraction of air can also be used to estimate variations in temperature, and the earliest thermometers, developed at the beginning of the seventeenth century, were based precisely on this principle.[2]

These early devices, which can be described as non-sealed air-thermometers, are the subject of the present paper. However, I do not aim at discussing anew the origin of the thermometer and much less at addressing the question of who invented it. Instead, I plan to investigate the factors which brought this specific experimental set-up to the attention of natural

[1] Newton D. E., "Wind", in: Newton D. E., *Encyclopedia of air* (Westport: 003) 208-213 esp. 209-210; Häckel H., *Meteorologie* 301-303.

[2] Particularly useful for the subject dealt with in this paper are some older publications on the origin of the thermometer: Caverni R., *Storia del metodo sperimentale in Italia*, vol 1 (Firenze: 1891); Hellmann G., "Beiträge zur Erfindungsgeschichte meteorologischer Instrumente", *Abhandlungen der preussischen Akademie der Wissenschaften, phys.-math. Klasse*, 1 (Berlin: 1920); Wohlwill E., "Zur Geschichte der Erfindung und Verbreitung des Thermometers", *Annalen der Physik*, 124 (1865) 163-178; Wohlwill E., Neue Beiträge zur Vorgeschichte des Thermometers, *Mitteilungen zur Geschichte der Medizin und der Naturwissenschaft*, 1 (1902) 5-8, 57-62, 143-158, 282-290. The most recent publicaton on the origin of the thermometer and the question of its inventor or inventors is: Taylor F. S. "The origin of the thermometer", *Annals of science*, 5 (1942) 129-156. Other monographies on the general history of thermometers and of the modern concept of temperature are : Bolton H.C., *Evolution of the thermometer 1592-1743* (Easton PA: 1900); Burckhardt F., *Die Erfindung des Thermometers und seine Gestaltung im XVII. Jahrhundert* (Basel: 1867); Golinski J., "Barometers of change: meteorological instruments as machines of enlightenment", in: Clarck W. -- Golinski J.-- Schaffer S. (eds.), *The sciences in Enlightened Europe* (Chicago: 1999) 69-93; Golinski J., "'Fit instruments': thermometers in eighteenth-century chemistry", in: Holmes F. L.-- Levere T. H. (eds.), *Instruments and experimentation in the history of chemistry* (Cambridge MA 2000) 185-210; Middleton W.E.K., *A history of the thermometer and its use in meteorology* (Baltimore: 1966); Renou E., *Histoire du thermomètre* (Versailles: 1876).

philosophers, eventually conferring it a significance which at times could rival that of weight-driven clockworks.

The starting point of my discussion shall be an anonymous experiment in natural magic involving air, water and fire, as well as a glass vessel. It was first described by Giovanni Battista Della Porta (ca. 1535-1615) in his *Four Books of natural magic* (1558), and I shall refer to it as 'the inverted-glass-experiment'.[3] The experiment consists in the following steps: (1) take an empty (i.e. air-filled) glass flask with a long neck, (2) heat it up, (3) turn it upside down, (3) plunge the extremitiy of its neck into a bowl full of water. After a while, as the air in the flask cools down, (4) observe the water in the bowl slowly rise up the neck of the inverted glass flask. The explanation of the phenomenon is that water rises because the air in the glass, in cooling down, contracts.

The fact that air expands under the action of fire, moving objects which stand in its way, had been known since antiquity. Devices based on this effect are described in the writings on pneumatics by Philo of Byzantium (c. 200 BC) and Hero of Alexandria (c. 62 AD).[4] This knowledge was passed on first to Arabic-Islamic scholars and craftsmen, and later to Renaissance engineers, who were particularly skilled in developing fountains based on both pneumatic and hydraulic effects.[5] However, the idea of making the phenomenon of expansion and contraction of air visible through glass seems to have occurred for the first time only to late Renaissance experimenters. This may have had much to do with the ready availability of glass vessels of all forms, used in alchemical experiments.

In the following pages, we shall follow the transformation in form and natural philosophical significance of the inverted-glass-experiment, from 1558 until the late 1620s, i.e. until that experimental set-up came to be regarded by many as an instrument to measure degrees of heat and cold. In the 1620s, the device was given a name which summed up its function: thermometer. As we shall see, though, the measure of heat and cold was only one side of a rather complex story, in which the technical artefact called thermometer could also be regarded as a perpetually moving weatherglass, demonstrating the activity of air and helping predict the weather.

The set-up of the inverted-glass-experiment is fully capable not only of measuring degrees of heat and cold, but also of perpetually moving and of responding to weather changes, sometimes even in advance. This is because, since the water bowl is open to the atmosphere,

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[3] Della Porta G. B., *Magiae naturalis sive de miraculis rerum naturalium libri IIII* (Anverse: 1560) 59r. All my references are made to the 1560 Anverse edition of this work. As Laura Balbiani has shown, the textual differences between the various editions are negligible (Balbiani L., *La 'magia naturalis' di Giovan Battista Della Porta. Lingua, cultura e scienza in Europa all'inizio dell'età moderna* (Bern: 2001) 23).

[4] For a brief overview on Philo's and Hero's work with further references, see Tybjerg K., "Hero of Alexandria's mechanical treatises: between theory and practice", in: Schürmann A. (ed.), *Geschichte der Mathematik und der Naturwissenschaften 3: Physik/Mechanik* (Stuttgart: 2005) 204-226. On the influence of Heron's Pneumatics see: Boas M., "Hero's Pneumatica: a study of its transmission and influence", *Isis*, 40 (1949) 38-48.

[5] Hollister-Short G., "The formation of knowledge concerning atmospheric pressure and steam power in Europe from Aleotti (1589) to Papin (1690)", *History of technology*, 25 (2004) 137-150; Prager F.D., "Fontana on fountains", *Physis*, 13 (1971) 341-360; Schmeller H., *Beiträge zur Geschichte der Technik in der Antike und bei den Arabern* (Erlangen: 1922) 26-27.

the height of the water column varies according not only to temperature, but also to external air pressure. As I shall argue, in the crucial, initial phase, it was the capability of making visible the activity of air which made the set-up interesting both for natural philosophers and for a wider audience.

This interest grew partly out of a heightened attention to weather phenomena, and partly out of a renaissance of philosophies of nature in which "spirit" or "spirits" acted as a medium between the corporeal and the incorporeal world. In this context, the inverted-glass experiment was seen as a demonstration of a new, anti-Aristotelian theory of the origin of winds. It did so by showing how air, when heated, could acquire moving force. Shortly afterwards, versions of the inverted-glass-experiment enjoyed a remarkable popular success as "perpetua mobilia", since the water in the glass moved slowly but incessantly without any apparent mechanical cause.

Later, the device's reactions to temperature changes became its prominent feature in the eyes of philosophers belonging to some specific schools of thought, notably both the Aristotelian Jesuits and the anti-Aristotelian friends and heirs of Galileo Galilei (1564-1642). However, those who followed another kind of non-Aristotelian view of nature, namely the one characterized by Allen Debus as 'chemical philosophy', continued seeing in the inverted-glass-experiment a visual proof of the holistic connection between microcosmos and macrocomos.[6] Thus, the history of the weatherglass/thermometer gives an example of how the same technological artefact could acquire different significances according to the philosophical framework of those approaching it. Yet this is not all. Studying the history of the inverted-glass-experiment also offers an overview of the many ways in which philosophers and technological artefacts could come into contact with each other in the early modern period. The inverted-glass-experiment was for some simply a literary description in Della Porta's widely read *Natural magic*. Yet there is no doubt that that experiment was also being carried out by some interested readers. Similar set-ups were also exhibited as marvels at courts or fairs, and those who could not attend the shows in person would perhaps see the artefact in sketches done by travellers. Some "virtuosi", having seen or heard of the device, actually built a replica of it.[7] Had they been unable to do so, they might have bought a copy: already in the 1620s, weatherglasses/thermometers were being produced and sold for profit. Finally, the popularity of such devices could be exploited by natural philosophers to make their own worldview accessible and acceptable to a broad public. In 1631, Robert Fludd (1574-1637) chose the weatherglass, by then a well-known instrument, and used it as a form embodying the whole of his cosmology.

Giovanni Battista Della Porta's ***Four books on natural magic*** *(1558): a marvel of glass, water, fire and air*

In his psychological portrait of Giovanni Battista Della Porta, the historian Mirko Grmek writes:

> There is something deeply tragic in the scientific work of Della Porta. For historians of science, the Neapolitan scholar is a man of missed opportunities. [...] It is only in retrospective, looking back at the events, that one notices how Della

[6]On chemical philosophy: Allen G. Debus, *The chemical philosophy: Paracelsian science and medicine in the sixteenth and seventeenth centuries*, 2 vols (New York, 1977).

[7] On early modern "virtuosi", see: Eamon W., *Science and the secrets of nature. Books of secrets in medieval and early modern culture* (Princeton: 1994) 301-318.

> Porta was lucky in the choice of certain subjects for his investigations, but unlucky in the their final outcome. We may take as an example magnetism, the thermometer, the camera obscura and the telescope.[8]

It is a fact that Della Porta has often been among the first ones to describe new technological devices, but never ended up being considered as their inventor. However, there is another, less tragic, way of looking at his work, namely seeing it as a privileged research ground to study the changing relationship between philosophy and technology in the early modern period.
Giovan Battista Della Porta was born approximately in 1535 from a noble but impoverished Neapolitan family, whose members cultivated a deep interest in classical and natural philosophical studies. He was probably educated privately, by tutors as well as by older members of the family. Already as a child, Della Porta was fascinated by the world of natural magic, both texts and experiments. He did not let financial difficulties stand in the way of his studies, travelling across Italy and Europe and partly financing his own experiments. He was helped by patrons like Federico Cesi (1585-1630). In 1603, Cesi founded in Rome the Accademia dei Lincei, which Della Porta joined in 1610. Della Porta published several works, but the most successful were the *Four books on natural magic* (1558), later expanded into a twenty books edition (1589). He also wrote books on specific issues of natural magic, as well as a number of plays in the Italian language. Significantly, the symbol and motto of the Accademia dei Lincei were taken from one of Della Porta's works. Because of his writings and his fame as a "magus", the Neapolitan author often had problems with censorship and perhaps also with the Inquisition.

The inverted-glass-experiment is described in Della Porta's earliest work, the 'Four books on natural magic', which was printed in its original Latin version in Neaples in 1558 and immediately enjoyed a Europe-wide success.[9] Between 1558 and 1588 it was reprinted more than fifteen times, for example in Anverse (1560), Lyon (1561), Cologne (1562) and Frankfurt (1585). The book was also translated into Italian (1560), Dutch (1566), French (1565) and German (1612), thus becoming accessible also to a less learned public. The reception of the work, both the positive and the negative one, was not only fast and intense, but also extended to an extremely varied readership. This fact is important for our subject, because it means that the experiments described in the book soon became known to a large, differentiated audience.

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[8] 'Il y a quelque chose de profondément tragique dans l'oeuvre scientifique de Della Porta. Pour les historiens des sciences, le savant neapolitain est un homme d'occasions manquées. [...] Ce n'est que rétrospectivement, en remontant les événements, qu'on constate combien Della Porta avait de la chance dans le choix de certains sujets de ses investigations et de la malchance dans leurs aboutissements. Prenons comme exemple le magnétisme, le thermométre, la chambre obscure et le télescope.', Grmek M. D., "Portrait psychologique de Giovan Battista Della Porta", in: Torrini M. (ed.), *Giovan Battista Della Porta nell'Europa del suo tempo* (Neaples: 1990) 17-30, quote taken from p. 27. My discussion of Della Porta's life and work is based on: Zaccaria R.-- Romei G., "Giambattista Della Porta", *Dizionario biografico degli Italiani*, 37 (1989) 171-182; Eamon W., *Secrets of nature* 195-233; Rienstra M. H., "Giambattista Della Porta", *Dictionary of scientific biography* 11 (1975) 95-98.

[9] The 'Four books on natural magic', are analysed in their contents, style and influence in: Balbiani L., *Magia naturalis*. Balbiani addresses the difficult question of the reception of the work on pp. 78-85 and offers an overview of its many editions and translations (Balbiani L., *Magia naturalis* 212-218.).

The *Four books on natural magic* were a collection of instructions on how to replicate and understand the secrets of nature.[10] According to Della Porta, the aim of natural magic was to replicate and understand the natural causes of marvels, i.e. of natural phenomena which are considered marvels by people who are ignorant of their real causes. Natural magic was, in this sense, 'natural philosophy brought to its highest perfection', and its practitioner, the 'magus', was a philosopher skilled both in performance and explanation of natural marvels.[11]

In the fourteenth chapter of the second book of the *Four books on natural magic*, Della Porta writes:[12]

> No less marvellous is the experiment where, if you want, an inverted vase draws up water.
> You shall do it so. Take a vase with a very long neck (the longer the neck is, the more marvellous [the experiment]), made out of glass and transparent, so that you shall see through it the water rise. Fill it completely with boiling water, and so it will become all very hot (or alternatively bring its bottom near to a fire), then immediately, lest it cool down, turn it upside down and put its mouth in the water, and it will absorb it all in itself. The explorers of the nature of things say that it is in this way that water is drawn up and absorbed by the rays of the sun from the caves of the earth in mountains, so that water springs originate. And no few artifices are derived from this in pneumatic machines, as Heron tell us, but such things are beyond our purpose, so let us go on to another subject.[13]

Della Porta's description of the inverted-glass-experiment is concise but clear, except possibly when he says that the glass vase should be filled with boiling water to make it hot, without specifying that it has to be emptied before plunging its neck into a (cold) water basin. The importance of using a glass vessel, through which the rising water can be observed is underscored. Interestingly, air is not even mentioned in this passage: the only elements explicitly appearing are fire and water. It is the water rising under the influence of fire that is being observed and interpreted as demonstrating how the sun draws up water from earth.

Della Porta does not claim to have invented the inverted-glass-experiment himself, and there is no reason to think that he did so. Possibly, he had not even performed it in person, when he wrote the *Four books on natural magic*. Nonetheless, the inclusion of the inverted-glass-

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[10] For a discussion of the scope, and sources of Della Porta's conception of natural magic, see Eamon W., *Secrets of nature* 210-217.

[11] 'naturalis philosophiae consumationem' Della Porta G. B., *Magiae naturalis libri IIII* 1r-1v.

[12] The relevance of this passage for the history of the thermometer was noted by Caverni R., *Storia*, vol. 1 270, and Hellmann G., "Erfindungsgeschichte" 10-11. More recent authors, instead, have failed to mention it: Taylor and Middleton, the latter probably following the former, quote another, similar experiment, which does not involve a glass vessel, and also convey the erroneous impression that Della Porta only dealt with thermal expansion of air in the second edition of the "Natural magic" (1589) (Taylor F. S.,"Origin" 133-134; Middleton W.E.K., *Thermometer* 5).

[13] 'Nec admirationis minus extat experimentum, cum voles, ut vas inversum aquam hauriat. Quod sic efficies. Longissimi colli paretur vas, et quo longius fuerit, eo mirabilius, vitreum vero, et pellucidum, ut ascendentem perspicies aquam, hoc bullientis aquae expletur, et ubi totum efferbuerit, vel igni fundum admoveto, illico, ne frigescat, inverso ore aquam tangat, et intro totam absorbeat. Sic naturae rerum exploratores Solis radiis aquam hauriri, et absorberi aiunt, e terrae concavis locis in montibus, unde fontanea efficitur scaturigo. Nec levia insurgunt hinc artificia, in spiritalibus machinis, ut tradit Heron, sed uti ab hoc proposito aliena, alio transferatur.' (Porta G. B., *Magiae naturalis libri IIII* 59r).

experiment in his successful book insured it a wide and rapid diffusion in Europe, setting in motion different, parallel processes of reception and reflection on the subject.

Giovanni Battista Benedetti: the rare, the dense and the origin of winds

A particularly relevant reflection was made by Giovanni Battista Benedetti (1530-1590), mathematician, astrologer and natural philosopher working in Turin at the court of the Duke of Savoy.[14] Benedetti was, before Galileo, the main Italian contributor to the mathematisation of natural philosophy. In 1585, he published a 'Book of various mathematical and physical speculations', containing also a collection of critical 'Disputations about some of Aristotle's opinions'.[15]

Chapter 34 of the 'Disputations' is devoted to 'Some questions on the rare and the dense, which have been discussed by the Peripatetics in a less than correct way'.[16] The chapter dealt with rarefaction and condensation of various substances, among them air. In full agreement with modern meteorologists, Benedetti explained that winds are caused by changes in the density of the air, which are in turn due to the heat of the sun. Thus, he opposed Aristotle's statement according to which winds are not moving air, but are made out of dry exhalations drawn up from the earth by the sun.[17]

> Nor can it be passed under silence that neither Aristotle nor any of his followers noticed that the dense and the rare are the cause of winds. Rare and dense happen through heat and cold and, if it is allowed to argue from the parts, in homogeneous things, to the whole, then everybody can reach the conclusions he prefers when observing that, in the hot days of summer, if some small cloud moves to cover the sun, immediately one can feel there an agitation of the air. And indeed, once the small cloud has gone further, and the air in that place has gone back to the original state of density caused by the sun, [the air] quiets down.[18]

Later in the chapter, Benedetti described the inverted-glass-experiment, albeit without explicitly using a glass vessel. He used it to contradict Aristotle's theory of the sun drawing up vapours and exhalations from the earth:

> We can demonstrate this with an experiment taking a vessel filled with nothing but air. If we first heat it up with a fire, and then [put it] with its mouth in a large bowl or some other vessel full of wine or water, we shall see in this way the fluid

[14] On the life and work of Giovanni Battista Benedetti, see: Cappelletti E., "Giovanni Battista Benedetti", *Dizionario biografico degli Italiani*, 9 (1966) 259-265; Drake S., "Giovanni Battista Benedetti", *Dictionary of scientific biography* 1 (1970) 604-609.

[15] Benedetti G.B., *Diversarum speculationum mathematicarum et physicarum liber* (Turin: 1585), containing the "Disputationes de quibusdam placitis Aristotelis".

[16] 'De raro et denso nunnulla, minus diligenter a peripateticis perpensa', in: Benedetti G.B., *Diversarum speculationum* 191-194.

[17] Gilbert O., *Die meteorologischen Theorien des griechischen Altertums* (Leipzig: 1907) 522-535.

[18] 'Neque silentium involvendum est, nec Aristotelem, neque alium ex suis fautoribus animadvertisse densum et rarum esse causam ventorum. Rarum autem et densum, mediante calore et frigore fit, et si a partibus, in omogeneis, licet argumentari, de toto deducat consequentiam qui velit, observans in calidis aetatis diebus, dum aliqua nubecula ad Solem cooperiendum incedit, ibi statim agitationem aeris sentiri, ea vero nubecula praetergressa cum fuerit, et in ea parte, aer ad pristinam raritatem causatam a calore Solis redierit, quiescit.' Benedetti G.B., *Diversarum speculationum* 192.

being immediately sucked up because, as the vase heats up, the air contained in it rarefies and, since it rarefies, it expands and, since it expands, it needs more space, and therefore a large part of it goes out [of the vessel]. As that part of air which has remained inside once again condensates, because the heat is gone, it contracts, and needs less space. Things being so, to prevent space from remaining empty, it is necessary that some other body should enter, since it is not possible for air to get in.

Thus, Aristotle was not correct in his meteors, book 1, chapters 9 and 10 and book 2, chapter 2, when he said that it is the heat of the sun which makes exhalations and vapours rise up. [He was wrong] because the sun does nothing but provide heat, and because of this heat, matter rarefies and it is because of rarefaction that it becomes lighter and ascends, and not because it is brought up by the sun.[19]

In this passage, Benedetti criticized an Aristotelian theory of the sun's action similar to that used by Della Porta in his *Four books on natural magic* to explain the inverted-glass-experiment, namely that heat attracts water. As we shall see in the following sections, in later publications Della Porta would modify his views on the subject and embrace Benedetti's explanation.

Della Porta's pneumatics and his reception of Benedetti

The second edition of the *Natural magic* (1589) described the inverted-glass-experiment almost with the same words as the first edition.[20] In the Italian translation of his *Three books on pneumatics* (1606), however, Della Porta gave a completely new description of the experiment.[21] The text is accompanied by a drawing, and it says:

Taking an ounce of air which is in its consistence [i.e. stable, in normal atmospheric conditions], one can easily measure in how many parts of finer air it can dissolve. And, although we have already dealt with this subject in our meteors, we do not mind repeating it, since it is appropriate at this point.

Let us take a flask for distillation called "gruale", or popularly named matras, in which one distils "aqua vitae" (i.e. alcohol), as described in our book on distillation. The flask shall be made out of glass, so that the effects of air and water will be visible. This will be vase A, and will have its mouth in a vase B, flat and full of water. That vase [i.e. the first one] will be full of air, which in its consistency shall be more or less thick according to place and season. Then bring

[19] 'Idem cum amphora in qua nullum alius, quam aereum sit corpus experiri possumus, si eam ad ignem primo calfactam, deinde cum ore in amplo aliquo cyatho, aut alio vase vino, aut aqua pleno ubi videbimus huiusmodi liquorem statim sursum ferri, quia dum calefit amphora, rarefit quoque aer qui in ea continetur, et quia rarescit dilatatur, et quia dilatatur, eget maiore loco, et ideo magna pars eius foras exit. Cum vero ea aeris portio, quae intus remanserit, iterum condensatur ob defectum caloris, restringitur, minorique indiget loco. Quod cum ita se habeat, necessarium est, ne aliquis locus vacuus remaneat, ut aliud quoddam corpus ingrediatur, cum ad ingrediendum aeri non patuerit aditus.Nec proprie locutus est Aristoteles 9. et 10. capite primi lib. et secundo secundi metheororum cum dixerit calorem Solis eum esse, qui sursum humores, vaporesque evehat, quia Sol nil alius facit, quam calefacere, cuius caloris ratione, ea materia rarefit, et ob rarefactionem levior facta ascendit, non quia sursum a sole feratur.' Benedetti G.B., *Diversarum speculationum* 193-194.

[20] Della Porta G. B., *Magiae naturalis libri XX* (Neaples: 1589) 288.

[21] Della Porta G.B., *I tre libri de' spiritali* (Neaples: 1606). The original Latin version of this work had appeared in 1601, but it did not contain any description of our experiment.

> a vase full of fire near the body of the vase A: the air, immediately heated up, starts to become more sublte and, once is it made more subtle, it wants more space and, trying to escape, comes out of the water, and one will see the water boil, which is a sign that the air is escaping. The more the air heats up, the more intensely the water boils, but, once the air has become most thin, the water will stop boiling. At that point, remove the vase with fire in it from the belly of A, and the air, cooling down, will become thicker and desire less space and, not having any way to fill the vase because its mouth is under water, will attract the water from the vase, and one shall see the water rise up with great fury, to fill all of the vase, leaving empty only that part where the air lies, reduced back to the nature it had in the beginning.
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> If you bring once again fire near to that little bit of air, it will again become thinner, and will push down all the water. Taking away the fire, the water shall rise up again. Once the water has stopped rising, mark with pen and ink on the outside of the glass the level of the water surface. Afterwards, letting out all the water from the vase, take another vase and fill the first one with water until it reaches the line you marked with ink. Then measure that quantity of water, and count how many times it has to be taken to fill the whole vase: that is the number of times by which a portion of air, taken at first in its consistence, shall enlarge when it is made more sublte by fire, and from here great secrets take their origin.[22]

I have quoted this description in full, because it is very interesting to compare it with the one Della Porta had given half a century earlier in his *Four books on natural magic*. Even though the phenomenon demonstrated is essentially the same, the description is radically different, both in style and in content. The older text was very schematic, only describing the essential features of the experiment. The new one, instead, offers, at least apparently, a real-to-life description. Moreover, in the new text air is not only explicitly mentioned, but even becomes the main protagonist of the show, like in Benedetti's work.

[22] 'Si può ancora agevolmente misurare un'oncia di aria nella sua consistenza in quante parti di aria più sottile si può dissolvere. E se bene di questo ne habbiamo trattato nelle nostre meteore, pur facendo qui a nostro proposito, non ci rincrescerà di ridirlo. Habbisi un vaso da distillare detto gruale, o volgermente detto materazzo, dove si distilla l'acquavuite, descritto da noi nel libro di distillare, e sia di vetro, acciò si vedano gli effetti dell'aria, e dell'acqua, e sia il vaso A, questo habbi la bocca dentro un vaso B, piano, pieno di acqua, il qual vaso sarà pieno di aria, grosso nella sua consistenza, più, e meno, secondo il luogo, e la stagione. Poi accostarete un vaso pieno di fuoco al corpo del vaso in A, e l'aria subito riscaldandosi, si andarà sottigliando, e fatta più sottile, vuole più gran luogo, e cercando uscir fuori, verrà fuori dell'acqua, e si vedr`s l'acqua bollire, che è segno che l'aria fugge, e quando si andrà più riscaldando, l'acqua più boglierà, ma essendo ridotta tenuissima, l'acqua non boglierà più, all'hora rimovete il vaso del fuoco dal ventre A, e l'aria rinfrescandosi, s'andrà ingrossando, e vuol minor luogo, e non havendo come riempir il vano del vaso, perchè ha la bocca sotto l'acqua, tirerà à se l'acqua dal vaso, e si vedrà salir l'acqua su con gran furia, e riempir tutto il vaso, lasciando vacua quella parte, dove sta l'aria ridotta già nella sua natura di prima. E se di nuovo accostarete il fuoco a quella poca aria, attenuandosi di nuovo, calerà giù tutta l'acqua, e rimovendo il fuoco, tornerà a far salir tutta l'acqua. Fermata cha sarà l'acqua, voi con una penna, et inchiostro segnarete fuori il vetro l'estrema superficie dell'acqua, poi lasicando uscir fuori tutta l'acqua della carrafa, all'hora con un'altro vaso porrete tanta acqua in detta carrafa, fichè riempirete infin al segno della linea notata con inchiostro: all'hora misurarete quell'acqua, e quante volte quell'acqua riempirà tutta la carrafa, tante volte una parte di aria nella sua consistenza si ampliarà, essendo attenuata dal caldo, e di qua nascono grandissimi segreti.' Della Porta G. B., *Spiritali* 76-77.

As before, particular importance is attached to the use of transparent glass, through which one can see. However, what is being observed now is not anymore the water rising and falling, but rather the air expanding and contracting. The vessel is identified as a specific tool used in alchemy, the 'matras', thus presenting the experiment in pneumatics also as an experiment in alchemy.

Della Porta's new description certainly had much in common with the one by Benedetti, strongly focussing on the expansion and contraction of air. It seems probable that he was influenced by Benedetti's reflections on the original experiment, and in turn developed them further. However, Della Porta made the most interesting use of the inverted-glass-experiment in his book on meteors: *On the transmutations of the air* (1610). Although this work was published in 1610, it must have been already in existence in 1606 because, as we saw, it is quoted in the Italian *Pneumatics*. In Della Porta's meteors, we shall find both the inverted-glass-experiment and a theory on the origin of winds very similar to the one offered by Benedetti. Before discussing that work, though, I will try and offer a short sketch of the role of meteors and their explanation in late Renaissance Europe.

Meteors in late Renaissance Europe

Weather phenomena - or better: meteors - had great importance in late Renaissance Europe, both for the explorers of the secrets of nature and for the broader public of the new medium, the press.[23] There is ample evidence to support this claim, and in the present section I shall offer an overview of it. However, it is well beyond the scope of this paper to discuss in general the role of meteorology in late Renaissance Europe, a subject which would surely deserve a thorough investigation. My aim is only to sketch the context in which the inverted-glass-experiment could, within a few decades, gain an extraordinary natural philosophical relevance. The evidence that I shall present is of various kinds: the growing amount of literature both on weather forecasts and on how to perform them; the popularity of reports and interpretations of extraordinary meteors; a net increase in the number of records of systematic weather observations, as well as in that of treatises explaining meteors, both within and outside of the Aristotelian tradition.

Ever since the late middle ages, weather forecasts had been a usual component of literature offering an overview on major events to be expected for the following year: astronomical events, religious festivities, seasonal and meteorological changes relevant to agriculture and medicine, as well as political events.[24]

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[23] On early modern meteors and their importance for natural philosophy: Zittel C., "Einleitung", in: Descartes R., *Le Méteores/Die Meteore. Faksimile der Erstausgabe 1637.* ed. C. Zittel, Zeitsprünge. Forschungen zur Frühen Neuzeit 10 1/2 (Frankfurt a. M.: 2006) 1-28 esp. 1-4.

[24] The following discussion of this kind of literature is based on: Biémont É., *Ritmi del tempo. Astronomia e calendari* (Bologna: 2002) 49-56; Casali E., *Le spie del cielo. Oroscopi, lunari e almanacchi nell'Italia moderna* (Turin: 2003) 35-60 (prognostications in general) and 141-145 (meteorological forecasts); Daxelmüller C. -- Keil G., "Prognose, Prognostik", *Lexikon des Mittelalters*, 7 (2002) c. 242-243; Hellmann G., "Wetterprognosen und Wetterberichte des XV. und XVI. Jahrhunderts. Facsimiliendruck mit einer Einleitung", in: Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, 12 (Berlin: 1899 repr. 1969) 7-26;

According to their contents, these texts can be roughly classified into almanacks, calendars and annual prognostications. Almanacks contained in the first place astronomical information, prognostications concentrated on predicting future events, and calendars listed the religious festivities for the year to come with the corresponding dates. However, by the middle of the sixteenth century no clear-cut distinction between the three types was possible anymore and all of them often included both a "calendar" in the modern sense and weather forecasts for the coming year. It is important to note this fact, because the connection between the word "calendar" and weather forecasts, which is lost today, helps explain the Latin name for the weatherglass: "vitrum calendare".

Calendars, almanacks and prognostications were among the first items to be printed after the invention of the press and, in the course of the sixteenth century, both their volume of production and their variety steadily increased, initially in Italy, later in all of Europe. The earliest printed texts were written in Latin, but soon versions in vernacular languages were produced. From the middle of the sixteenth century onward, predictions of political events came to be forbidden by the Catholic Church, but weather forecasts remained allowed.[25] Meteorological predictions for the following year were made on the basis of astrological computations, of traditional weather rules or by using a combination of both.[26]

The science of astrological weather forecasts, often indicated as "astrometeorology", which had its origin in Antiquity, had been greatly developed in the Arabic-Islamic middle ages, and later passed on to medieval Latin-Christian scholars, who appear to have taken a great interest in it, although they did not apparently employ it for agriculturally relevant predictions. In the Renaissance, all famous astronomers and astrologers published almanacks containing weather predictions.

In the course of the sixteenth century, not only weather forecasts, but also texts explaining how to perform predictions were printed, both treatises on astrometereology and collections of weather rules. A particularly successful item of the latter kind was the *Bauernpractick*, a booklet published for the first time in Germany in 1508, which saw more than fifty German editions and was soon translated into French, English, Dutch, Danish, Swedish and Norwegian.[27] The *Bauernpractick* explained how to predict the weather for the next year by observing it during the twelve days between Christmas and the Epiphany.

Maiello F., *Storia del calendario. La misurazione del tempo, 1450-1800* (Turin: 1996) 59-78; Plotzek J.M., "Almanach", *Lexikon des Mittelalters*, 1 (Munich: 2002) c. 445; Schuster P.-J. -- Grams-Thieme M., "Kalender, Kalendarium", *Lexikon des Mittelalters*, 5 (Munich: 2002) c. 866-867.

[25] Casali E., *Spie del cielo* 61-69.

[26] On astrological weather forecasts and on weather rules, see: Bos G. -- Burnett C. (eds.), *Scientific weather forecasting in the middle ages. Studies, editions, and translations of the Arabic, Hebrew and Latin texts* (London: 2000) 1- 95; Jenks S., "Astrometeorology in the middle ages", *Isis*, 74 (1983) 185-210; Maiello F., *Calendario* 49-58. On the combination of the two methods in the Renaissance: Casali E., *Spie del cielo* 142-143.

[27] Hellmann G. (ed.), "Die Bauern-Praktik (1508)). Facsimiliendruck mit einer Einleitung", in: Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, 13 (Berlin: 1896 repr. 1969).

Another constantly expanding kind of printed weather-related material were texts describing or interpreting extraordinary weather phenomena.[28] In particular cases, the growing quantity of printed material could in itself stimulate interest and participation on the part of the public, eventually giving rise to what has been considered as the first media-event in history: the astrological prediction of a Flood for the year 1524, an event which in reality never took place.[29]

While a broad interest in weather predictions and their interpretations was already present in the early sixteenth century, there are indications that, later in the century, meteors started attracting attention also as natural phenomena in themselves, and not simply as a possible danger or as a sign of future events. Evidence of this claim is of two kinds: a growing interest in systematic observations of weather and an increase in the number of treatises offering a description, classification and explanation of meteors.

Records of systematic weather observations concerning normal meteorological conditions and not only extraordinary events are preserved already from the late middle ages.[30] Those records were apparently kept by scholars engaging in astrological weather predictions. This trend was taken up by Renaissance astrologers like John Dee, and, in the late sixteenth century, weather observations were part of a program for reforming astrology in Louvain, one of the European capitals of prognostications. According to the historian Steven Vanden Broecke, this activity was not simply aimed at checking the accuracy of astrological predictions, but rather at constructing a 'reformed astrological physics'. Johannes Kepler, too, kept a record of meteorological observations, comparing observed weather and climate with astrological predictions in his defense of a reformed astrology.[31]

Most interestingly, a number of laymen users of calendars and almanacks noted by hand their own weather observations alongside the prognostications or the astronomical data for that date.[32] Systematic meteorological observations were also a relevant part of travellers' reports from the East and West Indies, and their statements, particularly those on tides, very soon

[28] Hellmann G., "Wetterprognosen" 21-26; Heninger S.K.jr, *A handbook of Renaissance meteorology with particular reference to Elisabethan and Jacobean literature* (Durham NC: 1960) 23-29; Jankovic V., *Reading the skies. A cultural history of English weather, 1650-1820* (Manchester: 2000) 33-44.

[29] Zambelli P., "Fine del mondo o inizio della propaganda? Astrologia, filosofia dellas toria e propaganda politico-religiosa nel dibattito sulla congiunzione del 1524", in: Garfagnigni G. (ed.), *Scienze, credenze occulte, livelli di cultura. Convegno internazionale di studi* (Firenze: 1982) 291-368.

[30] The following overview is based on: Hellmann G., "Meteorologische Beobachtugen vom XIV. is XVII. Jahrhundert", in: Hellmann G. (ed.), *Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus*, 13 (Berlin: 1901 repr. 1969) and Vanden Broecke S., *The limits of influence. Pico, Louvain, and the crisis of Renaissance astrology* (Leiden: 2004) 203-212.

[31] Kepler J., *Tertius interveniens. Warnung an etliche Gegner der Astrologie das Kind nicht mit dem Bade auszuschütten (1610)* (Frankfurt a. M: 2004) 111-112, 207, 251-252.

[32] Hellmann G., "Wetterprognosen" 10.

found their way into treatises of natural philosophy such as Girolamo Cardano's (1501-1576) *De subtilitate* (1550) and Francis Bacon's (1561-1626) *History of winds*.[33]

In fact, the European expansion overseas might have contributed to the interest in observing and explaining meteors, both because of the discovery of particularly notable new phenomena, such as the trade winds, and because of the unexpected climatic conditions to which settlers had to try and adapt, for example in North America.[34]

Let us now turn to the second kind of evidence for a general interest in the theory of meteors: the increasing number of treatises on the subject which were printed during the late sixteenth and early seventeenth century.[35] Ever since the thirteenth century, the main reference on the theory of meteors had been the Latin translation of Aristotle's *Meteors*. Soon after the invention of the press, this work was printed together with commentaries and summaries written both by ancient, medieval and contemporary authors. Around the middle of the century, though, a new kind of treatises on meteors started appearing: books written in the vernacular and explicitly aimed at a public of laymen. The earliest of them were Italian, for example Cesare Rao's (fl. 1560-1585) *I Meteori* (1582). Other books of this kind were Antoine Mizauld's *Brief et facile commentaire de toutes choses engendrée en l'air, comme pluyes, gresles, tonnaires, foudres, esclairs, neges, orages, vents, et autres* (Lyon 1558), and William Fulke's *A goody gallery with a most pleasant prospect, into the garden of naturall causes of all kind of meteors* (1571). Most of the original works still followed the guidelines of Aristotelian meteorology, explaining phenomena in terms of two exhalations, a humid and a dry one. At times, though, authors rejected some of Aristotle's opinions, quoting alternatives from other ancient authorities.

In the course of the sixteenth century, however, Aristotelian natural philosophy came under attack, especially in its geocentric cosmology and in its strict separation between superlunary and sublunary phenomena. In this context, some philosophers chose to formulate a new, not simply critical, but explicitly anti-Aristotelian theory of meteors.[36] In this category fall Cardano's chapters on meteors in the *De subtilitate*, Paracelsus' (1493-1541) De *meteoris* (1566), which was the first meteorology in German, Benedetti's reflections on winds, as well as two works in which the inverted-glass-experiment played a central role: Cornelis Drebbel's *On the nature of the elements* (1604) and Della Porta's *On the transmutations of the air* (1610). In 1627, Libert Froidmond (1587-1653) published his *Six books on meteors*, a book

[33] Nenci E., "Introduzione", in: Cardano G., *De subtilitate*, ed. E. Nenci, vol. 1 (Milan: 2004) 13-42, here 17-22; Ellis R. L. , "Preface to the 'Historia ventorum'", in: F. Bacon, *Works*, ed. J. Spedding--R.L.Ellis--D.D.Heath, vol 2 (London: 1859, repr. 1986) 1-6, here 4-5.

[34] Laskin D., *Braving the elements. The stormy history of american weather* (New York: 1996) 19-54. A strong case for interest in systematic, instrument-aided weather observations in Virginia is made by Sokol B.J., *A brave new world of knowledge: Shakespeare's The tempest and early modern epistemology* (Madison-Teaneck: 2003) 111-118.

[35] The following overview is based on Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches", in: Hellmann G. (ed.), *Beiträge zur Geschichte der Meteorologie*, vol 2 (Berlin: 1917) 1-134 and Heninger, S.K. jr., *Renaissance meteorology* 16-23.

[36] In Jankovic V., *Reading the skies* 22-24, Jankovich states that sixteenth and seventeenth centruy meteorologies remained essentially Aristotelian. While this statement might be applicable to the late seventeenth century, but certainly does not make justice of meteorology around 1600.

in which he responded critically to some of the new theories and offered a somehow reformed and updated version of Aristotelian meteorology.[37] His book would become a standard university textbook. Finally, as is well known, in 1637 Renée Descartes (1596-1650) published his *Meteors* as one of the appendixes to the *Discourse de la méthode* which had the aim of demonstrating the efficacy of his new method of pursuing knowledge.

Apparently, late Renaissance natural philosophers regarded meteors as a field in which to try and prove themselves superior both to the Aristotelian tradition and to their non-Aristotelian competitors, a fact possibly due to the growing public interest in weather phenomena. After the middle of the seventeenth century, instead, no new and innovative meteorological treatises appeared anymore.[38]

There are two more issues that deserve to be mentioned at this point, even though their relevance as evidence for an interest in meteors is not undisputable. The first one is the appearance of weather phenomena such as rain, dew or snow in literature, theatre plays and sermons, as well as in figurative art.[39] In the early seventeenth century, Dutch landscape paintings were developed, in which weather phenomena like snow and clouds were represented with great care. The latter fact is particularly interesting because, as we shall see, the Low Countries played a very important role in the history of the thermometer.
The second point to be made is that historic climatology tell us that the period between 1570 and 1620 was in average colder than the preceding and following one: it was the so-called "little Ice Age".[40] Even though it is difficult to estimate whether this phenomenon had any cultural consequences or not, it was apparently noted at least in central and Northern Europe, and might have been a reason prompting the invention of the above-mentioned Dutch winter landscapes and heightening the general sensitivity to weather and climate.

The question of the origin of winds

As a further premise to discussing Della Porta's meteors, it will be also useful to add a few general remarks on ancient and modern opinions on the origin of winds.
Already pre-socratic philosophers had stated that wind was nothing but moving air.[41] Aristotle, instead, had denied this, stating that what moved were only dry exhalations drawn up from the earth by the sun. Among the later philosophers who had voiced a clear opinion on the subject, some had agreed with the Stagirit, while others had gone back to the older opinion

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[37] Jankovic V., *Reading the skies* 24.

[38] Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 52.

[39] Goedde L.O., "Bethlehem in the snow and Holland on the ice. Climatic changes and the invention of the winter landscape, 1560-1620", in: Behringer W. -- Lehmann H. -- Pfister C. (eds.), *Kulturelle Konsequenzen der 'Kleinen Eiszeit'/Cultural consequences of the 'Little Ice Age'* (Göttingen: 2005) 311-322; Heninger, S.K. jr., *Renaissance meteorology* 153-214; Ossing F., "Der unvollständige Himmel. Zur Wolkendarstellung der holländischen Meister im 17. Jahrhundert", in: *Die 'Kleine Eiszeit': holländische Landschaftsmalerei im 17. Jahrhundert. Ausstellungskatalog* (Berlin: 2001) 41-54; Sokol B.J., *Brave new world*; Veit P., "'gerecher Gott, wo will es ihn/Mit diesen kalten Zeiten?'. Witterung, Not und Frömmigkeit im evangelischen Kirchenlied", in: Behringer W. -- Lehmann H. -- Pfister C. (eds.), *Little Ice Age* 283-310.

[40] Behringer W.-- Lehmann H. -- Pfister C., "Kulturelle Konsequenzen der 'Kleinen Eiszeit'? Eine Annährung an die Thematik", in: Behringer W.-- Lehmann H. -- Pfister C. (eds.) *Little Ice Age* 7-27.

[41] The following overview is basd on: Gilbert O., *Meteorologische Theorien* 511-539.

that wind was moving air. Among the latter were the Stoics who, according to Cicero's and Seneca's representations, had assigned to air a very important role in their cosmology.[42]
A modern meteorological definition of wind is 'any flow of air'.[43] At the same time, though, winds are recognized as being extremely complex phenomena, for which no general explanation can be offered beyond saying that air moves from a region of higher pressure to one of lower pressure.[44] On a planetary scale, it is the heat of the sun which, by making air expand, sets in motion atmospheric air masses. At the equator, where the maximum heating effect occurs, air rarefies and expands more than in the tropical regions. However, expanding air does not simply push away colder air, but instead, having become lighter, rises up. In this way, a low-pressure area is created around the equator, and colder, thicker air from the tropics rushes in to fill the gap. Thus, as European seamen noted in the sixteenth century, trade winds blow the whole year around from tropical areas towards the equator, both in the northern and in the southern hemisphere.[45] These winds were a puzzle whose solution was offered by Edmond Halley (1656-1742) and later refined by George Hadley (1685-1758). Most winds experienced in temperate areas, though, cannot be regarded as resulting directly from thermal expansion, because they are mostly due to local geophysical structures and to the effects of the movement of air masses in tropical areas.

However, even before Halley and Hadley, other natural philosophers had advanced the opinion that the cause of winds should be seen in the thermal expansion of air under the action of the sun. The first one was apparently the Arabic-Islamic scholar Al-Kindī, while the second might have been Benedetti.[46] A short time later, the same theory was stated by Della Porta and by Cornelis Drebbel.

Della Porta's ***Transmutations of the air*** *(1610)*

Della Porta's book *On the transmutations of air* (1610) is an anti-Aristotelian treatise on meteors.[47] The work has been recently made accessible in an edition offering details on its large number of references to classical authors. However, its natural philosophical contents have not yet been analysed in detail.[48] It is not possible for me to offer here such an analysis, but I will summarize those statements which are relevant for the subject at hand.

As we shall see, Della Porta's meteorology was influenced both by Stoic natural philosophy and by contemporary alchemical theories. Moreover, in at least two key questions the Neapolitan philosopher referred to new technological developments. The first one was the origin of winds, which I shall discuss presently. The second one was the cause of thunder and lightning, which Della Porta identified with explosions of a substance similar to gunpowder.[49]

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[42] Barker P., "Stoic contributions to early modern science", in: Osler M.J. (ed.), *Atoms, 'pneuma', and tranquillity. Epicurean and Stoic themes in European thought* (Cambridge: 1991) 135-154, here 138-139.

[43] Newton D. E., "Wind" 209.

[44] The following overview on modern wind theories is based on: Häckel H., *Meteorologie* (Stuttgart: 2005) 252-268 and 301-303; Newton D. E., "Wind".

[45] On trade winds, see: Fierro A., *Historie de la météorologie* (Paris: 1991) 69-70.

[46] Bos G. -- Burnett C. (eds.), *Scientific weather forecasting* 345-346.

[47] Della Porta G. B., *De aeris transmutationibus,* ed. A. Paolella (Neaples: 2000).

[48] Purnell F.Jr., "Review of G. B. Della Porta 'De aeris transmutationibus'", *Renaissance quarterly,* 55 (2002) 748.

[49] Della Porta G. B., *De aeris transmutationibus* 148-149.

This kind of explanation had been put forward by Paracelsus and had been taken up and expanded by many of his followers, as we shall see later on.[50]

For Della Porta, meteors were not simply "changes" in the air, but actual "transmutations" in the alchemical sense: as shown in a table right at the beginning of the book, air could transform both into fire and water, thus originating all kinds of meteors.[51]

> Since I am about to write about meteors, it shall be good to start from the air itself, because air completely fills the space between heaven and earth, and contributes matter and basis to all aerial impressions. When it fluctuates, it gives rise to winds, when it is more strongly excited and made thinner, to fire and thunder; contracted, [it gives rise] to clouds, when it becomes thicker, to rain; when it freezes, to snow and when it is frozen and made denser in a more turbulent way, to hail. When it is relaxed, it makes fair weather.[52]

Della Porta supports his opinion with quotes from Pliny the Elder's (23-79) *Natural History* and Seneca's (4 BC - 65 AD) *Natural questions*. Seneca's Stoic views on the active role of air as life-carrying medium linking heaven and earth receive particular attention:

> On this subject, Seneca says: 'thus air is part of the world, and a necessary one. Air is what links heaven and earth [...] It gives to what is above all that it receives from the earth; it infuses heavenly force in earthly things' [..] Air is the cause making all animals live."[53]

As Della Porta pointed out, air gave men and animals the breath of life, and actively carried sounds to the ear, smells to the nose and images to the eye.[54] In discussing air and its qualities, Della Porta rejected Aristotle's theory that it is warm and dry and, once again following the Stoics, assigned to it one single quality: coldness.[55] He concluded that 'air is the vehicle of all which is 'spirabilis' and is susceptible to heavenly influences', where the term "spirabilis" can mean "air-like" or "life-giving".[56]

The first phenomenon which Della Porta discussed was the purest form of motion of air: the wind. He argued against Aristotle's theory of winds, according to which winds are not moving air, but are made out of dry exhalations rising up from the earth and rather agreed with the view stated by Seneca that the origin of wind was to be sought in the air's power of moving

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[50] Debus A.G., "The Paracelsian aerial niter", *Isis*, 55 (1964) 43-61.

[51] The transmutations are summed up in a table: Della Porta G. B., *De aeris transmutationibus* 11.

[52] '*De Metheoris* tractaturo, bene erit ab aere ipso exordiri, is namque inter coelum et terram totus interiicitur, et materiam et fundamentum impressionum aerearum omnium praebet. Nempe fluctuans ventos facit, vehementius concitatus et attenuatus igem et tonitrua, contractus nubila, conspissatus pluviam, congelatus nivem, et turbulentius gelatus addensatusque grandinem, et distensus serenum facit' Della Porta G. B., *De aeris transmutationibus* 14.

[53] 'Seneca ad haec: 'sic mundi pars est aer, et quidem necessaria. Hic est enim qui coelum terramque connectit [...]. Supra se dat quicqid accepit a terris; sursum vim syderum in terrena transfudit.' [...] Hic causa est ut cuncta animalia vivant.' Della Porta G. B., *De aeris transmutationibus* 14-15.

[54] Della Porta G. B., *De aeris transmutationibus* 15.

[55] Della Porta G. B., *De aeris transmutationibus* 15-17.

[56] 'Est tandem aer spirabilium rerum vehiculum et caelestium influxuum suceptivus.' Della Porta G. B., *De aeris transmutationibus* 17.

itself, thanks to which it 'sometimes thickens, sometimes expands and purifies itself, or otherwise contracts, escapes and moves away'.[57] Finally, after offering a very broad spectrum of ancient opinions (and even a few medieval ones), Della Porta stated his own view on the subject. He did this by describing the inverted-glass-experiment in the same way he had done in his Italian *Pneumatics*.[58]

The experiment was supposed to help understand the origin of winds, showing how the sun would heat up the air, which expanded both upwards and to the sides, pushing away the colder air which was near to it. As we saw in the previous chapter, this theory is nearly - but only nearly - correct. Della Porta referred to the same example brought up by Benedetti: the wind which rises in summer when a cloud covers the sun.

> One might argue that, in summer days, when a cloud intercepts the light of the sun, in that shadow we immediately feel a breeze and an agitation of the air: the reason is that, because of the absence of heat, air reverts to its previous state and invites the air surrounding it which with its arrival refreshes us and, once this air has diffused or gone further, the breeze stops.[59]

There can be no doubt that Della Porta was influenced by Benedetti's reflection on air, fire and wind. However, for Benedetti, the origin of winds was only one among a large number of subjects in which he contradicted Aristotle's views. For Della Porta, instead, the subject becomes one of the pillars of a new theory of meteors. The explanation Della Porta gave was simple and plausible, but it was incorrect and hardly had any explanative power with respect to observable winds. Nonetheless, the theory was advocated not only by Benedetti and Della Porta, but also by the Dutchman Cornelis Drebbel, to whom we shall turn in the next section.

Cornelis Drebbel: his life and work

Cornelis Drebbel of Alkmaar in the Netherlands (ca. 1572-1633) is a historical figure well exemplifying the characteristics of the late Renaissance 'magus'.[60] In fact, the figure of Cornelis Drebbel may have inspired William Shakespeare (1564-1616) in creating Prospero, the king-magician of *TheTempest*, while Drebbel's machines were a model for some of those described by Francis Bacon in his *New Atlantis*.[61] In her monography *The body of the artisan: art and experience in the scientific revolution* (Chicago: 2004) Pamela H. Smith counts Drebbel among the Dutchmen representing the 'artisanal epistemology articulated by

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[57] '[aer] modo spissat se modo expandi et purgat, alias contrahit, deducit ac differt.' Della Porta G. B., *De aeris transmutationibus* 39.

[58] Della Porta G. B., *De aeris transmutationibus* 43-45.

[59] 'Argumento esse poterit, quod aestivis diebus, cum opaca nubes solis lumen intercipit in ea umbra statim aura ac aeri agitatio praesentitur: ratio quia caloris absentia, aer ad pristinam sedem se convertendo ad se cirumfusum aerem invitat, qui novo adventu nos refrigerat, at diffusa vel praeterlapsa, quiescit aura.' Della Porta G. B., *De aeris transmutationibus* 45.

[60] On Drebbel's life and work, see: Harris L. E., "ornelis Drebbel of Alkmaar" in: Harris L.E., *The two Metherlanders: Humphrey Bradley and Cornelis Drebbel* (Cambridge: 1961) 121-227; Jaeger F. M., *Cornelis Drebbel en zijne tijdgenooten* (Groningen: 1922); Tierie G., *Cornelis Drebbel (1572-1633)* (Amsterdam: 1932).

[61] Colie R.E., "Cornelis Drebbel and Salomon de Caus: two Jacobean models for Salomon's House", *Huntington Library Quarterly*, 18 (1954/55) 245-260; Sokol B.J., *Brave new world* 102-111 and p. 118-124.

Paracelsus', according to which 'certainty was to be extracted from nature through bodily experience'.[62]

Other than Della Porta, Drebbel has been granted a prominent place in all discussions on the origin of the thermometer. This is hardly surprising, since he was considered the inventor of that instrument by numerous contemporary authors, as well as by later authorities such as John Henry Lambert (1728-1777).[63] In the seventeenth century, the non-sealed air-thermometer often went under the name of 'Drebbelian instrument'. However, even though Drebbel engaged in almost all kinds of experimental activities, he never made the slightest attempt at estimating degrees of heat and cold. Modern historians have established this beyond any doubt. What did he do, then, to have his name attached to the thermometer?

Drebbel's life was equally divided between court and workshop. As a young man, he became an apprentice to Hendrik Goltzius (1558-1617), an artist, engraver and alchemist who had set shop in Haarlem. Drebbel not only worked with Goltzius as an engraver, eventually marrying his sister Sophia, but he also engaged both in engineering and in natural philosophy. By 1604 he had been granted patents for a water pump, a self-regulating, perpetually moving clock, had built a fountain in Middelburg, had become a close friend of the philologist and hermetist Gerrit Pieterzoon Schagen (1573-1616) and had published a *Short treatise on the nature of the elements and how they cause wind, rain, lightning and thunder and to what they are useful* (1604).[64] The book was written in Dutch and, while its original edition is very rare today, it was again printed, possibly with modifications in 1621, 1688, 1701/02 and 1732. Within a few years it was translated into German (1608, repr. 1619, 1624, 1628, 1715, 1723), Latin (1621, repr. 1628, 1702) and French (1672).[65] No English version of Drebbel's treatise exists, and neither was the Latin version of the book printed in England: this is somehow surprising, since Drebbel spent large part of his life in London.[66]

In the Netherlands, Drebbel conceived a "perpetuum mobile" which, as we shall see, was in more than one sense a weatherglass. In 1604, or shortly after that, he moved to London, where he succeeded in attracting the attention of King James I (reg. 1603-1625), to whom he presented his "perpetuum mobile", which was later put on show in Eltham palace. In 1609, the Dutchman was attached to the retinue of James's son Henry (1594-1612). Already in 1610 Drebbel left London for Prague, accepting an invitation of the emperor Rudolf II of Hapsburg (reg. 1576-1612).

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[62] Smith P.H., *The body of the artisan: art and experience in the scientific revolution* (Chicago: 2004) 162-164. The quote on artisan epistemology is from p. 155.

[63] Burckhardt F., *Erfindung* 6-7; Lambert J. H. , *Pyrometrie oder vom Maaße des Feuers und der Wärme* (Berlin: 1779) 13-15; Wohlwill E., "Erfindung" 163-166.

[64] 'Een kort tractaet van de natuere der elementen, ende hoe sy veroorsaecken, den wind, reghen, blixem,donder, ende waromme dienstlich zijn', title quoted from the edition printed in Haarlem in 1621. For a list of the editions and translations of this work, see: Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 77-80, 84-86.

[65] The earliest edition of the treatise which was accessible to me was the German translation: Drebbel C., *Ein kurzer Tractat von der Natur der Elementen und wie sie den Wind, Regen, Blitz und Donner verursachen und war zu sie nutzen* (Leiden: 1608), from which all my references and quotes are taken.

[66] The English translation Hellmann lists with a question mark in Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 77 was no translation, but an original work by Thomas Tymme.

For many years, Rudolf II had been drawing to his court the most renowned - and sometimes the most ill-famed - artist, philosophers, astrologers/astronomers and natural magicians, among them John Dee (1527-1608), Tycho Brahe (1546-1601) and Johannes Kepler (1571-1630).[67] Giovanni Battista Della Porta had been invited there, too, but had declined. In Prague, Drebbel engaged in alchemy and built a new version of his "perpetuum mobile". In 1611, though, Rudolf's brother Matthew of Hapsburg (1557-1619) invaded Prague with the support of the Bohemian protestants and effectively deposed Rudolf, who died one year later. According to a later account, Drebbel was at first imprisoned, but later released and even invited to remain at the new court. He chose to travel back to England, instead.

From this time onward, it becomes difficult to reconstruct Drebbel's movements, but it seems he spent most of his time in England, where he anyway never attained again royal patronage, in large part because Prince Henry had died in 1612. Nonetheless, Drebbel continued producing marvels, among them a submarine, as well as optical instruments and furnaces, which sold quite well. In his old age, he ran and alehouse in London, to which clients were attracted by his fame as a magician.

Drebbel's treatise ***On the nature of the elements*** *(1604)*

Cornelis Drebbel's *Short treatise on the nature of the elements, and how they cause winds, rain, lightning, thunder and why they are useful* was first published in Dutch in 1604 and, as we saw, enjoyed a great popularity for the next 100 years, especially in Germany and the Netherlands.[68] Therefore, it can be assumed that Drebbel's ideas had a nonnegligible influence on European natural philosophy, although this question has not yet been the subject of a systematic study.

Drebbel's treatise is profoundly different from Della Porta's. It is written in the vernacular and contains no quotes from the classic authors. Instead, it begins and ends with intensely religious remarks on how the study of nature attracts men to God, remarks that led the historian Gerrit Tierie to the conclusion that Drebbel was an anabaptist.[69] The contents of the book, however, are clearly influenced by alchemical practice and thought, containing, like Della Porta's meteors, the gunpowder theory of thunder and lightning.[70] Moreover, Drebbel, like Paracelsus, represented Creation as a process of chemical separation of the four elements out of an initial, undistinguished mass.[71] The Dutchman used the four Aristotelian elements, and not Paracelsus' "tria prima", but he established a clear hierarchy between them:

> Thus God separated His creation into four parts: fire, air, water and earth, and each has its power according to its subtlety. In this respect, fire is superior to all other elements and has the power to give them a clearness similar to its own. Fire

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[67] Grudin R., "Rudolf II of Prague and Cornelis Drebbel: Shakespearean archetypes?", *Huntington library quarterly*, 54 (1991) 181-205, esp. 182-183.

[68] A brief overview of the text, underscoring its Paracelsian character, can be found in Smith P.H., *Body* 162-163. The book is quoted as an original contributio n to meteorology by Hellmann G., "Entwicklungsgeschichte des meteorologischen Lehrbuches" 49-50. Jankovic V., *Reading the skies* 180 recognizes that the text was influential, but inexplicably describes it as 'neo-scholastic'.

[69] Tierie G., *Drebbel* 18-19.

[70] Drebbel C., *Kurzer Tractat* [21]. Since the pages of this edition are unnumbered, my references are made by counting from the title page, and are given in square brackets.

[71] Drebbel C., *Kurzer Tractat* [7-9]. On alchemical Creation see: Debus A.G., "Aerial niter" 52.

> gives life to all things and without it all things are dead, as we see everyday, especially in winter.[72]

Under the action of fire, air becomes like fire, water like air and earth like water.[73] Fire 'is the life of everything' and it is thanks to the fiery action of the sun on air and on the other elements that plants and animals live.[74] In Drebbel's explanation of weather, the interplay between fire, air and water was very important, as it is also in modern meteorology. In the fourth chapter, Drebbel explained wind and rain by saying that the sun made air similar to fire and water to air, so that the two would rise and move around spreading humidity.[75] Eventually, when air-like water had risen up to where the air was cold, it turned again into water proper and fell down. At this point the air stood still. The way in which fire caused wind was demonstrated by way of the inverted-glass experiment, which was shown in the only picture appearing in the treatise [Fig. 1]:

Fig. 1: The inverted-glass-experiment as represented in: Drebbel C., *Kurzer Tractat von der Natur der Elemente und we sie den Wind, Regen, Blitz und Donner veursachen und war zu sie nutzen* (1608).

> [We see this] when we hang a glass retort with its mouth in a vase with water, and put a warm fire under the belly [of the retort], as this image instructs and explains. As soon as the air in the glass begins to become warm, we shall see that winds rise out of the mouth of the retort, and that the water fills with bubbles. And this will increase, as, with time, the air becomes warmer. But if we take away the

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[72] 'Also hat Gott sein Geschopf in vier theil geteilet: Feuer, Luft, Wasser und Erde und ein jegliches hatt seine Kraft, darnach sein Subtilitet ist darin das Feuer alle überrifft, und hat Macht ihnen eine Klarheit seiner Klarheit gleich zu machen, es gibt allen Dingen Leben, und sonder im seindt alle Dinge todt, wie wir alle Tag und vornehmlich im Winter sehen,' Drebbel C., *Kurzer Tractat* [8].

[73] Drebbel C., *Kurzer Tractat* [9, 12-13].

[74] Quote 'Also ist klar, das das Feuer das Leben ist von allem' is taken from Drebbel C., *Kurzer Tractat* [11].

[75] Drebbel C., *Kurzer Tractat* [14-15].

> retort from the fire, and the air begins to cool down, the air in the retort will again shrink, becoming coarse and thick, so that the glass will fill with water.[76]

Drebbel's and Della Porta's descriptions of the experiment are very similar. The Dutchman, too, emphasized the alchemical nature of the experience by using a retort. The accompanying picture represented the experiment as taking place under a tree and not in a laboratory, underscoring its natural character. Like Della Porta, Drebbel, too, explained how important it was to use a glass vessel, so that the activity of air can be seen.[77] However, quantification of the phenomenon could not be further from Drebbel's thoughts. Another difference is the fact that Drebbel, while describing the air escaping from the vessel as "wind", did not claim that expanding air simply pushes cold air away. In fact, he raised doubts about such an explanation, and he did this in connection with the same phenomenon discussed by Benedetti and Della Porta.

> One might ask: how come then, that in summer we often feel the wind coming from the clouds and not from the place where water is made thinner and rises, a fact apparently contradicting what has been said until now?[78]

Drebbel's answer was that, in this case, wind was due to the fact that clouds cool down, sink and thus press on the air below them, causing it to escape on the sides.[79] Apparently, the Dutchman had noticed the discrepancy between his theory and observations, but did not know how to explain it in general.

Meteors, alchemy and pneumatics

Drebbel and Della Porta shared an interest not only in weather, but also in alchemical thought and pneumatic experiments. Although a direct influence of Drebbel on Della Porta cannot be ruled out, I would like to argue that the similarities between the two works can be traced back to a particular current of late Renaissance natural philosophy in which meteors, alchemy and pneumatics stood near to each other.

Even though Paracelsus had been the first one to use alchemical patterns to explain meteors, tradition had linked alchemy and meteorology long before him, as the two disciplines studying the characteristics and behaviour of the four elements. The fourth book of Aristotle's *Meteors* dealt with themes related to what later would be known as alchemy.[80] Moreover, alchemists were in a particularly good position to explain meteors, because

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[76] '[...] wan wir hangen eine ledige glaserne Retortam mit dem Mund in ein Fas mit Wasser und unter dem Bauch ein warm Feuer legen, wie diese figur ausweiset und mitbringt. So werden wir sehen, sobald der Lufft im Glas anfangt warm zu werden, das Winde steigen aus dem Mund der Retorten und das Wasser voller Blasen wird, und dis wirdt mehren, so lange der Lufft je lenger ie wermer wird, aber wenn du due Retorte vom Feuer nimbst, und der Luft wieder in der Retort ineinander gehen grob und dicke werden also das Glas wirt mit Wasser erfullet werden.' Drebbel C., *Kurzer Tractat* 15-16.

[77] Drebbel C., *Kurzer Tractat* 16.

[78] 'Es möchte einer fragen, wie kommt es dan, das wir oftmals im Sommer den windt aus den Wolcken fühlen und nicht aus den Ort da das Wasser verdünnet, ode aufgezogen ist, welches dem vorigen zu wieder?' Drebbel C., *Kurzer Tractat* 19.

[79] Drebbel C., *Kurzer Tractat* 19-20.

[80] Pepe L., "Introduzione", in: Aristotle, *Meteorologia*, ed. L. Pepe (Milano: 2003) III-XXVI, esp. XIX-XXVI.

knowledge of the thermodynamic properties of water, water vapour and air was, and still is, essential to make sense of weather phenomena. Such knowledge could certainly be acquired by performing alchemical experiments.

Another way to learn about the properties of air and water, though, was the study and construction of pneumatic machines such as those described by Hero of Alexandria and built by Renaissance engineers. The philosophical significance of those devices had already been recognized by Cardano, who had included some of Hero's devices in his *De subtilitate*.[81] At that time, clockwork mechanisms had long entered philosophy to serve as models for conceiving cosmic order, and Descartes would even use them as a pattern to explain all bodily functions of living creatures. Less mechanically and mathematically-minded philosophers might instead have taken an interest in developing the philosophical potential of those technological novelties which, like alchemical experiments and pneumatic devices, could not (yet) be represented in geometrical-mathematical terms.

Thus, alchemy and pneumatics might have been not so far from each other in the eyes of some early modern philosophers, and they both could contribute to a better understanding of (at least some) meteors.

However, the inverted-glass-experiment did more than offer a plausible, anti-Aristotelian explanation of the origin of winds. In fact, as we saw, the explanative potential of the model was noticeably reduced by the wrong assumption that hot air would simply push away cold air. In my opinion, the fascination of the experiment was largely due to the fact that it offered a visual demonstration of the otherwise invisible activity of air under the influence of fire. This activity could be interpreted as the cause not only of wind, but of all atmospheric phenomena. In the next section, I will try to show how this feature, too, mirrored a general trend of late Renaissance natural philosophy.

Spirit, air and fire in late Renaissance Europe

Both Drebbel and Della Porta saw meteors as product and vehicle of a fiery, vital principle of heavenly origin, whose nature was neither fully corporeal nor fully incorporeal.
For Drebbel, the principle was the element fire, the most subtle part of Creation, which clarified air and the other elements, living in them and giving them life. Della Porta's views were stated mostly by way of classical quotes and are not completely clear. However, he attributed to air the capability of carrying - or even actually transmuting into - a fiery spirit originating in heaven, which made life on earth possible.

This aspect of Drebbel and Della Porta's theory of meteors can be seen as part of a general tendency in Renaissance philosophy: explaining natural phenomena as resulting from the action of one (or more) subtle substance, neither fully corporeal nor fully incorporeal, variously referred to as "spiritus", "pneuma", "quintessence" or, sometimes, simply fire, air or wind.

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[81] Boas M., "Hero's Pneumatica" 41; Nenci E., "Introduzione" 22-27.

It is not possible for me to offer here more than a rough sketch of this complex subject, whose various aspects have been dealt with in a large number of articles and monographies.[82] The origins of the various concepts of "spirit" as medium between corporeal and incorporeal elements of the cosmos can be traced back to Antiquity.[83] Stoicism, Neoplatonism and Aristotelian-Galenic medicine had each developed its own specific form of such a concept. These, in turn, had influenced the Fathers of the Church in their reflections on the Holy Spirit, until with Augustinus a definitely non-corporeal conception of the third divine person established itself.[84] However, the term "spiritus" retained in the middle ages and in the Renaissance an ambiguous character, and it could be used to indicate both corporeal entities like air, breath or wind and incorporeal entities like the human soul.[85] As we saw, treatises on penumatics could be titled 'Spiritali'.

All these traditions were either still alive or were revived in the Renaissance, when the philosophical potential of various ideas of "spirit" was fully exploited. Particularly important was Stoic cosmology, as expounded by Cicero and Seneca.[86] For the Stoics, "spiritus" or "pneuma" was a mixture of air and fire which brought life from the celestial regions onto the earth and at the same time brought back from earth nourishment for the celestial beings. In Stoicism there was no clear-cut dichotomy between matter and soul, and the whole world was considered as animated. Stoic pneuma had both corporeal and incorporeal features and could be seen both as a breath of life and as a divine, immanent intelligence. Stoic philosophy reached Renaissance thinkers both directly, through ancient sources, and indirectly, by way of the influence it had previously had on Neoplatonism and medicine. Stoic concepts were often found in Renaissance texts on natural philosophy and alchemy, and played a prominent role in challenging Aristotelian worldviews. As far as the study of meteors is concerned, Stoicism was particularly relevant, since it had a long tradition of paying attention to such phenomena

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[82] On the various concepts of "spirit" and their interaction and assimilation in the late Renissance: Debus A.G., "Chemistry and the quest for a material spirit of life in the seventeenth century", in: Fattori M. -- Bianchi M. (eds.), *Spiritus . IV° colloquio internazionale* (Roma: 1984) 245-263; Garin E., "Relazione introduttiva", in: Fattori M. -- Bianchi M. (eds.), *Spiritus* 3-14; Klier G., *Die drei Geister des Menschen. Zur sogenannten Spirituslehre in der frühen Neuzeit* (Stuttgart: 2002); Putscher M., *Pneuma, spiritus, Geist. Vorstellungen vom Lebensantrieb in ihren geschichtlichen Wandlungen* (Wiesbaden: 1973); Walker D.P., *Spiritual and demonic magic from Ficino to Campanella* (Leiden: 1958); Walker D.P., "Medical 'spirits' and God and the soul", in: Fattori M. -- Bianchi M. (eds.), *Spiritus* 223-244.

[83] On the concept of "pneuma" in Antiquity, see: Verbeke G., *L'évolution de la doctrine du pneuma du stoicisme á S. Augustin* (Paris: 1945, repr. 1987).

[84] Verbeke G., *Pneuma* 507-508.

[85] Armogathe J.-R., "Note brève sur le vocabulaire de l'âme au dix-septième siècle", in: Fattori M.-- Bianchi M. (eds.), *Spiritus. IV° colloquio internazionale* (Roma: 1984) 325-331; Bautier A.-M., "'Spiritus' dans les textes antérieurs à 1200. Itinéraire lexicographique médiolatine: du souffle vital à l'au delà maléfique", in: Fattori M. -- Bianchi M., *Spiritus.* 113-132; Hamesse J., "Spiritus chez les auteurs philosophiques des 12e et 13e siècle", in: Fattori M. -- Bianchi M., *Spiritus* 157-190.

[86] On ancient Stoic doctrines of pneuma: Verbeke G., *Pneuma* 11-174, summary on p. 172-174. On Stoic influence on Renaissance natural philosophy: Barker P., "Stoic contributions"; Joly B., "Présence des concepts de la physique stoicienne dans les textes alchimiques du XVIIe siècle", in: Margolin J.C. -- Matton S. (eds.), *Alchimie et philosophie à la Renaissance* (Paris: 1993) 341-354.

and explaining them, for example winds and tides, as due to the activity of the all-pervading pneuma. A Stoic work largely devoted to meteors was, of course, Seneca's *Natural questions,* so often quoted by Della Porta.[87]

Another source for ideas on "spirit" in the Renaissance was Neoplatonic philosophy, which was rediscovered and reshaped in the fifteenth century. In Marsilio Ficino's (1433-1499) *Three books on life* (*De vita libri tres*, 1489), the 'spirit of the world' ('spiritus mundi') was the mediator between matter and the fully immaterial 'soul of the world' ('anima mundi').[88]

> [Spirit] is a very subtle body; as it were not body and almost soul. Or again, as it were not soul and almost body. Its power contains very little earthy nature, but more watery, still more aerial and the maximum of fiery and starry nature [...] It vivifies everything and everywhere and is the immediate cause of all generation and motion.[89]

Similar conceptions of spirit and spirits were part of Renaissance natural magic, where they worked as mediators between macrocosmos and microcosmos.[90] The spirit of the world interacted with an analogous spirit present in human beings, the astral body, which connected body and soul. The astral body was a Neoplatonic concept which some Renaissance authors assimilated to yet another traditional concept of "spirit", that of Aristotelian-Galenic medical spirits.[91]

Medical spirits were the instruments through which the soul controlled the body. Originally, they were considered as corporeal: a fine, hot vapour which was a main component of live breath and of arterial blood. In some Renaissance authors, though, they could also be thought of in Neoplatonic terms, as a middle substance between body and soul, conveying both vital heat and the influence of the stars.

As has been shown by many historical studies, all these conceptions of "spirit", though in principle radically different from each other, in the Renaissance could interact or be assimilated to each other, eventually raising again questions on the corporeal nature of the Holy Ghost.[92]

Even though conceptions of spirits were developed in all branches of Renaissance philosophy, they were particularly important in alchemical thought.[93] Paracelsus and his followers were undoubtedly influenced by ancient tradition, but the development of alchemical practice had

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[87] On pneuma in Seneca's work, see: Verbeke G., *Pneuma* 143-157.

[88] On Ficino's "spiritus": Walker D.P., *Magic* 12-13, 22-23; Garin E., "Relazione introduttiva" 6-8.

[89] '[Spiritus] vero est corpus tenuissimus, quasi non corpus, et iam anima. Item quasi non anima, et quasi iam corpus. In eius virtute minimum est naturae terrenae, plus autem aquae, plus ite aeriae, rursusignae stellaris quamplurimum [...] Ipse vero ubique viget in omnibus generationis omnis proximus author atque motus.' Both the Latin text and the English translation are quoted the English from Walker D.P., *Magic* 13.

[90] On Renaissance spiritual magic: Walker D.P., *Magic*.

[91] Klier G., *Drei Geister* esp. 21-62; Walker D.P., "The astral body in Renaissance medicine", J*ournal of the Warburg and Courtauld institutes*, 21 (1958), p. 119-133; Walker D.P., "Medical 'spirits'".

[92] Walker D.P., "Medical 'spirits'".

[93] Figala K., "Quintessenz", in: Priesner C. -- Figala K. (eds.), *Alchemie. Lexikon einer hermetischen Wissenschaft* (Munich: 1998) 300-302; Hild H., "Geist", in: Priesner C.-- and Figala K., *Alchemie* 147-148; Joly B., "Pneuma", in: Priesner C. -- Figala K., *Alchemie* 284-285.

added new material which stimulated interest in and reflection on the role of "spirit" in nature. An alchemical pattern to think about not-quite-corporeal substances had been provided by the discovery of how to distil the 'spirit of wine', which Paracelsus indicated with the name of 'alcohol vini', i.e. 'the most subtle part of wine'.[94] Like alcohol in wine, "spirits" or "quintessences" were allegedly present in all kinds of bodies as pervading, subtle substances that could not be isolated mechanically, but only alchemically, through distillation. Ideally, iterating the process of distillation an appropriate number of times on the right ingredients, one might eventually obtain "the" quintessence, i.e. the philosopher's stone.

A further alchemical pattern for thinking vital spirit were explosive substances. In the Paracelsian corpus, a fiery spirit variously indicated as "salpeter", "aerial niter" or "nitrous salt", analogous to the corresponding earthly substances, was assumed as present in the air.[95] It was considered to be the cause of thunder and lightning, a necessary "food" for living creatures and the origin of some fiery diseases. This theory was further developed by Joseph Du Chesne (1544-1609), who described the vital niter of the air as an ingredient of salpeter, which was seen as a life-giving substance produced by a process of cosmic distillation. We may recognize the similarity to the theory of meteors proposed by Drebbel. In the seventeenth century, the idea of a life-giving "aerial niter" or "flamma vitalis" present in the air and responsible for respiration, combustion, thunder and lightning as well as, according to some authors, for snow and earthquakes became quite common.[96]

Even though they were particularly important for alchemists, "spirits" in the ambiguous sense discussed above played a prominent role also, for example, in the works of Francis Bacon.[97] According to the reconstruction by the historian Graham Rees, in his speculative philosophy Bacon made large use of the concept of "spiritus vitalis", a mixture of fire and air which conferred living beings most of their faculties.[98]

The brief overview on the role of spirit and spirits in Renaissance natural philosophy has hopefully shown how the inverted-glass-experiment, when presented as a visual demonstration of activity of fiery air, could not fail to attract attention. As already noted, air, and especially wind, were traditional candidates for a corporeal manifestation of spirit. Moreover, in the Holy Scriptures, particularly in the Old Testament, winds played a very important role both as weather phenomena and as manifestations of the divine.[99] In the Bible, a large number of quotations could be found to support the double interpretation of the term

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[94] Quoted from: Stillman J.M., *The story of alchemy and early chemistry* (New York: 1923 repr. 1960) 192. In general on this subject: Figala K., "Quintessenz"; Taylor F. S., "The idea of the quintessence", in: Underwood E. A. (ed.), *Science, medicine and history. Essays in the evolution of scientific thought and practice written in honour of C. Singer*, vol 1 (London: 1953) 247-265.

[95] Debus A.G., "Aerial niter", especially p. 48; Guerlac H., "The poet's nitre", *Isis*, 45 (1954) 243-255.

[96] Debus A.G., "Aerial niter" 59-61. In particular, on aerial niter and meteors: Guerlac H., "The poet's nitre" 250-254.

[97] Fattori M., "'Spiritus' dans l''Historia vitae et mortis' de Francis Bacon", in: Fattori M. -- Bianchi M. (eds.), *Spiritus* 283-323, Rees G., "Francis Bacon and 'spiritus vitalis'", in: Fattori M. -- Bianchi M., *Spiritus* 265-281; Walker D.P., "Francis Bacon and 'spiritus'", in: Debus A.G. (ed.), *Science, medicine and society in the Renaissance*, vol 2 (London: 1972) 121-130.

[98] Rees G., "Francis Bacon" 275-276.

[99] Sevrin J.-M., "'Spiritus' dans les versions latines de la bible", in: Fattori M. -- Bianchi M., *Spiritus* 77-91.

"spiritus" which was common in the middle ages. Winds also featured prominently in a pivotal text for alchemical thought: *The Emerald Table*, which began with the words:

> True it is, without falsehood, certain and most true. That which is above is like to that which is below, and that which is below is like to that which is above, to accomplish the miracles of one thing.
>
> And as all things were by contemplation of one, so all things arose from this one thing by a single act of adaptation.
>
> The father thereof is the Sun, the mother the Moon.
>
> The wind carried it in its womb, the earth is the nurse thereof.[100]

It is worth noting that the *History of the winds* (1622) was the first part of Francvis Bacon´s *Natural history*.[101] In this work, he expounded a theory on the nature and origin of winds which was a mixture between traditional Aristotelian doctrine and the ideas of Benedetti, Drebbel and Della Porta.[102]

Therefore, the special significance acquired by the inverted-glass-experiment in Drebbel's and Della Porta's treatises was neither a coincidence nor the result of direct influence. It was rather a quite successful attempt at applying to a new field of great public interest, i.e. the study of meteors, new and rapidly developing forms of natural philosophical thought. These new trends reflected not only more or less abstract, esoteric traditions, but also new developments in medical, alchemical and pneumatic-hydraulic experience, and used them to demonstrate to the senses the analogical unity of microcosmos and macrocosmos.

This style of theorizing was anything but homogeneous, but eventually came to be associated not only with philosophical, but also with political and religious protest under the label of "Rosicrucianism".[103] On the natural philosophical level, it found two main opponents: on the one side the Catholic church and its official Aristotelian worldview, usually represented by the Jesuits, on the other side the representatives of a mathematical-mechanical, often corpuscolarist worldview, like Galileo and, later, Renée Descartes. Even though these two groups were at odds on many questions, notably Copernicanism, they both argued for a clear-cut distinction between corporeal and incorporeal and both favoured mechanical, i.e. clockwork-type devices as models for natural philosophical thought.

The meteorological opinions of each group found expression in two works already mentioned: Libert Froidmont's Aristorelian *Six book on meteorology* and Descartes's corpuscolarist *Meteors*. Right at the beginning of the section dealing with winds, Froidmont attacked ancient and modern theories defining wind as moving air, and particularly the 'Stoic dreams' of air as 'animal' capable of moving out of its own will.[104] Descartes, instead, explained winds

[100] The quote is taken from: Linden S. J. (ed.), *The alchemy reader. From Hermes Trimegistos to Isaac Newton* (Cambridge: 2003) 28, which reproduces a transaltion by. R. Steele and D. Waley Singer, Proceedings of the Royal Society of medicine 21 (1928) p. 486. On the special position of winds in Renaissance anchemy, see also: Böhme G. - Böhme H., *Feuer Wasser Erde Luft. Eine kulturgeschichte der Elemente* (Munich: 1996) 235-240.

[101] Ellis R. L. , "Preface to the 'Historia ventorum'".

[102] Bacon F., "Historia ventorum", in: Bacon F., *Works*, vol 2 13-78, here especially 46-48.

[103] Gilly C., "Die Rosenkreuzer als europäisches Phänomen im 17. Jahrhundert und die verschlungenen Pfade der Forschung", in: Gilly C.--F. Niewöhner (eds.), *Rosenkreuz als europäisches Phänomen im 17. Jahrhundert* (Amsterdam: 2002) 19-56.

[104] 'aer animal non est, ut somniant Stoici.' Froidmont L., *Meteorologicorum libri sex* (London: 1656) 178.

mechanically, as due to the pressure of vapours of various kind and of course he, too, denied air any active role.[105]

In the next section, we shall see how Cornelis Drebbel contributed to speculations about the moving power of air, not only with his writings, but also with his most famous invention: a perpetual motion machine.

Drebbel's "perpetuum mobile" and its trapped spirit

Thanks to a thorough search in printed and manuscript sources, historians have collected a large amount of evidence on the structure and function of Drebbel's "perpetuum mobile".[106] In fact, it would be more correct to speak of "perpetua mobilia", since the Dutchman built more than one version of the device. As far as we can tell, though, they were all based on the expansion and contraction of air which caused water to move right and left inside a curved glass tube. The more complex versions of the device also featured a self-regulating clockwork showing the calendar date and the position of the stars, although it is impossible for us to say how (and whether) these parts actually worked. In this paper, the main interest rests on the movement of the water, which was the most prominent feature of the machine in the eyes of its beholders. There can be no certainty on how the device was really built, since none are extant, but, according to reconstructions by contemporaries and historians, it was composed of a hollow metal sphere and of a circular glass tube larger than the sphere, which was fixed around it, passing above and below it [Fig. 2].

[105] Descartes R., *Méteores* 94-99.

[106] The most recent collection and discussion of the sources relevant to Drebbel's device and its reception in Europe is: Drake-Brockman J., "The 'perpetuum mobile' of Cornelis Drebbel", in: Hackmann W.D. -- Turner A. J. (eds.), *Learning, language and invention. Essays presented to Francis Maddison* (Ashgate: 1994) 124-147. However, I will challenge her interpretation of the reception in terms of a doomed old philosophy of Aristotelian and/or Rosicrucian inspiration clashing with new natural philosophy represented by Galileo's circle (Drake-Brockman J., "perpetuum mobile" 146-147). Further discussions of Drebbel's device are: Michel H., "Le mouvement perpetuel de Drebbel", *Physis*, 13 (1971) 289-294; Tierie G., *Drebbel* 37-42, Harris L. E., "Drebbel" 149-159.

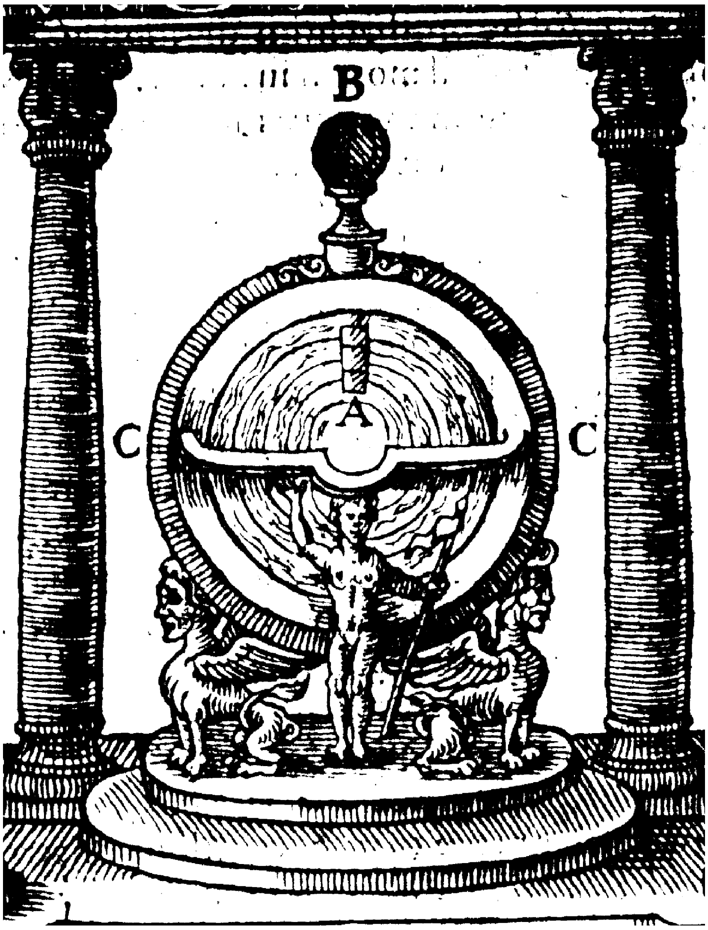

Fig. 2: Drebbel's perpetual motion device as represented in: Tymme T., *A dialogue philosophicall: wherein natures secret closet is opened and the cause of all motion in Nature shewed out of matter and forme. Together with the wittie invention of an artificial perpetual motion (by Corn. Drebbel)* (1612) (detail).

The glass tube was divided in two by a partition at its uppermost point. To the left side of the partition, the inside of the glass tube was connected to the inside of the sphere. On the right side, instead, the tube was perforated and communicated with the atmosphere. The glass tube was half-filled with water, so that the air on the left side was trapped between the water surface, the walls of the tube and those of the sphere. On the right side, the air was free to enter and exit the glass tube. When the air trapped in the spherical reservoire heated or cooled, the water level sank or rose on the left side of the tube, and consequently rose or sank on the right side. The same movement took place also when atmospheric pressure increased or decreased.

If this reconstruction is accurate, Drebbel's device was nothing but a fanciful form of the set-up for the inverted-glass-experiment.

The earliest evidence of Drebbel's perpetuum mobile is in a letter written in London, in all probability in 1604.[107] The writer, John Speed, saw the device before it was presented to King James I, was fascinated by its motion and even made a sketch of it. In the letter he stated, among other things:

> Round about the east and west parts doth a ring or hollow trunke of christall stand and that without moving and the same filled to his halfe with fayre water, which

[107] Drake-Brockman J., "perpetuum mobile" 125-127. On p. 125, the sketch is reproduced.

> without any instrument that can be perceived doth ebb and flow with the Seas in every part of the world, my self stayed so longe that I sawe it ascend up the trunk a good height and left the lower compasse of the ringe empty.[108]

In 1607, Drebbel presented his perpetual motion device to James I, and we have an eyewitness account of that moment in the travel diary of Heinrich Hiesserle von Chodaw, a gentleman from Bohemia.[109] The description shows Drebbel's theatrical skills in the way he half-explained the device to the king. Particularly interesting for us is the following remark:

> The King then asked again from what the perpetual motion derived its power, to which he answered shortly, saying that it was the Air, the principal element, which made all things move.[110]

This explanation is correct from the modern scientific viewpoint, but also fits in with the spiritual trend in Renaissance natural philosophy discussed in the previous section. An early evidence of the context in which Drebbel intentionally placed his "perpetuum mobile" is contained in a work published in 1607 by Drebbel's friend Gerrit Schagen. The book contained:

(1) four short extracts praising Archimedes' sphere, three taken from ancient authors and one from a contemporary one, (2) a letter written by Drebbel to James I, to offer him his "perpetuum mobile", later translated into Latin and often published together with other works by Drebbel, and (3) Schaden's translation from Italian into Dutch of the *Pymander*, a Hermetic treatise from late antiquity.[111]

The parallel between Archimedes's sphere and Drebbel's machine was later taken up by many authors.[112] Archimedes' device was a kind of armillary sphere i.e. a mechanism geometrically representing the cosmic spheres. Although it was probably water-driven, only the motion of its mechanical parts was philosophically relevant. Thus, Drebbel's pneumatic perpetual motion was assimilated to mechanical clocks, which, from the philosophical point of view, were arguably the most relevant technological development of the late medieval and early modern period. Drebbel's "perpetuum mobile", however, not only showed celestial motion, but also made its moving force visible, as the Dutchman wrote to James I:

> Knowing ebb and flow, I build an instrument which continually ebbs and flows each 24 hours, perpetually showing the months and their days, the phases of the moon and the hours, and the tides. [...] This is the offshoot or a branch of the tree of perpetual motion, rooted in the real knowledge of the elements.[113]

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[108] I quote after Drake-Brockman J., "perpetuum mobile" 125. The text is taken from Bodleian Library MS Ashmole 1813, f. 374.

[109] Drake-Brockman J., "perpetuum mobile" 128-129.

[110] I quote from Drake-Brockman J., "perpetuum mobile" 128. The text is translated from the original German contained in: Heinrich Hiesserle von Chodow, Raiss Buch und Leben, Pague Nat. Mus. vi A 12, ff. 48v-50r.

[111] 'Wonder-vondt van de eeuwige bewegingh, die den Alckmaersche Philosooph Cornlis Drebbel door een eeuwigh bewegende gheest in een Cloot besloten te weghe gebrocht heeft welchers toeeygeningh (in 't vereerendes selvigen aen den grootmachtigen Coningh Jacob van groot Brittangen) allhier naecktelijck vertoont wordt.'A facsimile reproduction of the work can be found in: *De Alkmaarder Cornelis Drebbel. Uitvinder, hermetist, alchemist* (Harlem: 2005).

[112] On the parallel between Drebbel's machine and Archimedes' sphere: Drake-Brockman J., "perpetuum mobile" 143.

[113] 'At cognitione fluxus et refluxus eficio instrumentum semper fluens et refluens singulis 24 horibus, ostendens menses eorumque dies, cursum lunae et horas, fluxus et refluxus in perpetuum. [...] Illud est propago vel surculus

Here, Drebbel linked the motion of the water with that of the tides. This explanation will have certainly appeared plausible to many spectators, since moving water was the most prominent feature of the "perpetuum mobile". However, it was wrong and Drebbel knew it, having himself offered the right one both in his treatise and in his explanation to James I. Possibly, the Dutchman was acting like a natural magician should, providing a philosophical bait for those who wanted to learn more. If they read his treatise, experimented in first person or asked repeatedly, like the king had done, they would learn the true cause of the motion, i.e. the activity of air.

Popularity of and reactions to Drebbel's "perpetuum mobile"

Probably also thanks to the theatrical skills of its inventor, in the following decades, Drebbel's perpetual motion machine attained Europe-wide fame. After it was put on show in Eltham Palace, it became so well know, that it was used in jokes by Ben Jonson (1573-1637) and by other satirical writers.[114] According to some historians of literature, the "perpetuum mobile" might even have provided inspiration for Shakespeare's description of Ariel as an imprisoned spirit.[115] As contemporary paintings show, small replicas of it were being sold to wealthy clients for their cabinets of curiosities.[116]

Further evidence of how Drebbel's machine or devices similar to it had become a commercial success is found in a remark made by the physician Henri de Heer (1570-1636) in a polemic writing addressed to Jan Baptista van Helmont (1577-1644). Van Heer argued that water can transform into air, and brought the following evidence:

> To demonstrate the idea of perpetual motion, and at the same time show which part of the house is warmer, which colder and which temperate, a smart mathematician has build a glass in which he, with great understanding, completely enclosed air together with some red water [...]. And what happened? In my house as well as in many other places, the precious water disappeared and was therefore transformed into air, since there was no other way out. The whole of Liège, His Highness the Prince, the whole court and I do not know how many visitors of Spa have held these glasses in their hands, have looked in and have felt sorry for the transformation of the water into air, because in that moment the mathematical marvel had ceased to be.[117]

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arboris perpetui mobilis, insitus verae cognitionis elementorum.' I quote from the Latin translation printed as an appendix to: Drebbel C., *Tractatus duo: prior de natura elementorum, posterior de quinta essentia* (Hamburg: 1621) [11]. Since the pages of this work are unnumbered, Ma reference is made by counting from the title page of Drebbel' letter.

[114] Sokol B.J., *Brave new world* 106-111.

[115] Grudin R., "Rudolf II" 192-193. The connection between the Tempest and weatherglasses/thermometers is a central theme of Sokol B.J., *Brave new world* esp. 102-124.

[116] Michel H., "Mouvement perpetuel" 290-291.

[117] It was unfortunately impossible for me to access the original, Latin version of this text, which is taken from: Heinrich van Heer, Deplementum supplementi de Spadanis fontibus (1624) so I translate here the German translation found in Wohlwill E., "Neue Beiträge" 145-146: 'Ein scharfsinniger Mathematiker, um uns den Begriff einer immerwährender Bewegung anschaulich zu machen und zugleich erkennen zu lassen, welcher Teil des Hauses wärmer, welche kälter, welcher mäßig kühl sei, ein Glas hergestellt, in dem er sinnreich ein tiefrotes Wasser [...] mit Luft vollkommen eingeschlossen hatte. Aber was geschah? Sowohl in meinem Haus wie an

Van Heer did not give a description of the glass, but van Helmont, in his answer, did so. From his description it appears that what the 'smart mathematician' was selling as a "perpetuum mobile" was nothing else than a simplified version of Drebbel's device. It had the form of a J-shaped glass tube, open at its lower end and partially filled with water. Could the seller have been Drebbel himself or was is only an imitator? Maybe one of his sons-in-law, whom we know took part in his commercial enterprises? Whatever the answer, this passage shows how pneumatic perpetual motion was becoming a commercial success in Northern Europe. There is also evidence that, in 1620s, such devices appeared also in Italy: from a letter of Cesare Marsili (1592-1633) to Galileo we learn that in Bologna, in the year 1626:

> A certain engineer passed by, who claimed that, using some salty or marine water, he showed in certain glass flasks the motion of ebb and flow of the sea caused by celestial and intrinsic virtue.[118]

In his answer, Galileo explained that the motion was in all probability due to thermal expansion and contraction of the air, on which he had experimented twenty years before, and had nothing to do with the tides. Marsili replied:

> What I had written you about the flasks showing ebb and flow of the sea has turned out to have no substance, but they had a different use, which I however have not been able to see up to now, even though I hope I shall be able to do so in a short while.[119]

Unfortunately, from Galileo's correspondence we learn nothing more about the real use of the flasks, and we may only speculate whether it had to do with perpetual motion, thermoscopy or weather forecasting. In any case, there can be no doubt that the device shown was some form of the inverted-glass-experiment which was starting to circulate in Italy, too. We shall come back to the J-shaped tube and its special relationship to the Netherlands in a later section: let us now return to Drebbel.

The fame of Drebbel's machine was responsible for the fact that the non-sealed air-thermometer became known as a 'Drebbelian instrument', a term used already around 1625 in the Netherlands, to indicated both Drebbel's "perpetuum mobile" and the instrument to measure the temperature of the air.[120] What is particularly relevant for our subject, though, is that the device brought the apparently active character of air to the attention of a broader public. After the initial marvel, many philosophical discussions arose on the subject, as ample evidence shows.[121] The perpetual motion was seen by some as demonstrating a primal moving force of nature, while others interpreted it as a trivial application of a well known,

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verschiedenen anderen Stellen ist das kostbare Wasser verschwunden und in Luft übergangen, denn einen anderen Ausgang gab es nicht. Ganz Lüttich, der durchlauchtigste Prinz, der ganze Hof, unzählige Besucher von Spaa haben diese Gläser in Händen gehalten und gesehen, haben die Verwandlung des Wassers in Luft schmerzlich bedauert, denn im selben Augenblick war es aus mit dem Wunder der Mathematik.' The following discussion is based on: Wohlwill E., "Neue Beiträge" 147-150.

[118] 'Un certo ingegniero, qual pretende con certa acqua salsa o marina mostrare in certe ampolle i moti dei flussi et reflussi de' mari, cagionati per celeste et intrinseca virtù.' Galilei G., *Opere*, vol 13 316. The letters I discuss here are edited in: Galilei G., *Opere*, vol. 13 316-317, 319-320, 326, 327-328.

[119] 'Quanto le havevo scrito di quel'ampole, che mostravano il flusso e riflusso del mare, era riuscito una vanità, ma havevano un uso differente, il quale però sin ad hora non ho potuto vedere, anchorchè fra poco lo speri.' Galilei G., *Opere*, vol. 13 326.

[120] 'Drebbeliaensche instrument' (Beeckman I., *Journal*, ed. C. De Waard, vol. 2 (La Haye: 1942) 361, 361n3.

[121] Drake-Brockman J., "perpetuum mobile" 141-145; Harris L. E., "Drebbel" 156-158.

philosophically not particularly relevant phenomenon. Among those who shared the first opinion were many 'chemical philosophers'. One of them was Thomas Tymme (fl. 1566-1612) who, having previously translated into English the works of the Paracelsian Joseph Du Chesne, in 1612 published a book titled: *A dialogue philosophicall: Wherin natures secret closet is opened and the cause of all motion in Nature shewed out of matter and forme. Together with the wittie invention of an artificiall perpetual motion (by Corn. Drebbel).*[122] Drebbel's 'artificial perpetual motion' was described, discussed and represented in an engraving. Like Drebbel and Schagen, Tymme, too, regarded the device as a visual demonstration of the principle of all motion.

A completely different reaction was that of Daniello Antonini (1588-1616), who belonged to the circle of Galileo.[123] In the year 1612, Antonini wrote to Galileo from Brussel that he had heard of James I's perpetual motion machine 'in which water moves up and down in a glass tube, like (as they say) the ebb and flow of the sea.'[124] He had also seen a drawing of the device and had thought about it, concluding that the movement must be caused by the heating and cooling of the air in the tube. His conclusion was based on the 'speculations on those experiments with the large glass' which Galileo knew about, obviously some form of the inverted-glass-experiment.[125] This is the earliest evidence explicitly connecting the inverted-glass-experiment with Drebbel's device. Antonini did not limit himself to speculations: he went immediately from thought to action and built a model of the machine, which he later presented to Albert of Austria. Proudly he described to Galileo how he had explained to an incredulous audience that he had discovered the secret of the device.

Drake-Brockman interprets this episode in the context of a clash as between an old-fashioned magical-philosophical stance and the emerging scientific worldview.[126] In my opinion, this interpretation is too reductive, and it is incorrect to contrast Antonini's and Drebbel's attitudes as respectively scientific and non-scientific. Antonini sought the cause of motion in mechanical terms, explaining the movement of water as due to the force of expansion and contraction of air under the influence of heat, by then a well known phenomenon. Having reached this conclusion, he did not go further, asking for example why air would acquire moving force under the action of heat. This is today a scientifically very relevant question, answered in terms of energy. In the early seventeenth century, those who marvelled at the perpetual motion and asked the same question, often answered it in terms of fiery spirits. Thus, the same technological artefact could inspire different reflections according to the natural philosophical views of the beholder. However, it is very important to note a

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[122] On Thomas Tymme see: Debus A.G., *The English Paracelsians* (New York: 1966) 87-97. The role of Drebbel's pertpetual motion in Tymme's book is discussed in detail in Harris L. E., "Drebbel" 152-155. Inexplicably, in Jankovic V., *Reading the skies* 180-181 Tymme's treatise is erroneously attributed to Drebbel.

[123] On Antonini's short life, see: Galileo G., *Opere*, vol 20 (1968) 372-373. The letters which I summarize here are edited in: Galileo G., *Opere*, vol 11 (1968) 269-270 and 275-275.

[124] 'nel quale entro un canale di vetro si move certa acqua, hor alzandosi hor abbassandosi, a guisa (dicevasi) del flusso e del reflusso del mare.' (Galilei, G., *Opere*, vol 11 269).

[125] 'speculazioni di quelle esperienze del bellicone' (Galilei, G., *Opere*, vol 11 270).

[126] Drake-Brockmann claims that 'the "perpetuum mobile" was the product of a thoroughgoing Aristotelian cosmology' (Drake-Brockmann J., "perpetuum mobile" 146) and at the same time describes Drebbel's claims to knowledge of perpetual motion as part of a 'doomed Rosicrucian obsession' (Drake-Brockmann J., "perpetuum mobile" 147).

characteristic which Drebbel and Antonini shared: they both were ready to let technological artefacts influence their philosophical reflections.

Santorio Santorio and Aristotelian degrees of heat and cold

Santorio Santorio (1561-1636) was born in Capodistria, at the time part of the Venetian Republic, had studied medicine in Padua and had worked as a physician first in Croatia and later in Venice.[127] Thanks to his ability as a physician and to the success of his first book on Galenic medicine, in 1611 he became a professor of theoretical medicine in Padua, where he lectured, practised and published the results of his medical experiments, mostly in the form of commentaries to classical medical texts. In 1624 he retired from university activity, but continued practising and publishing.

Despite being based on Aristotelian-Galenic theories, Santorio's work was deeply original. He attributed great importance to experiment and especially to operational quantification. To this end, he devised a number of instruments for measuring, among other things, rapidity of the pulse and humidity as well as weigh loss and gain due to ingestion, excretion and perspiration.[128] In 1614, he wrote a treatise *On static medicine* which had an immediate success and remained highly appreciated for longer than a century.

Among the instruments Santorio used, there was one whose function was to determine degrees of heat and cold. It was identical with the set-up for the inverted-glass-experiment. Santorio mentioned it briefly for the first time in his commentary to Galen and described it more in detail later, in his commentary to Avicenna's canon.[129] In the latter work, the device was shown in a picture and described in these words:

> The image is a glass vase thanks to which we can very easily, in every hour determine the cold or hot temperature, and we can learn every hour in a most perfect way how much the temperature deviates from the natural state measured before. This vase is put by Hero to another use. We have adapted it so that it serves to discern the cold and hot temperature of the air, and of all parts of the body, and to learn the degree of hotness of those who have fever.[130]

Later on, Santorio described various versions of his device for measuring the 'hot or cold temperature' of a patient.[131] He also used the instrument to determine the temperature of the

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[127] My overview on Santorio's life and work is based on: Grmek M.D., "Santorio Santorio", *Dictionary of scientific biography*, 11 (1975) 101-104. On Santorio's device to measure degrees of heat and cold see: Taylor F. S., "Origin" 129-132 and 135-140. Caverni R., *Storia*, vol 1 265-270.

[128] For a description of all of Santorio's instruments and a collection of the corresponding original quotes, see: Grmek M.D., *Santorio Santorio i njegovi aparati i instrumenti* (Zagreb: 1952) 64-70.

[129] Santorio S., *Commentaria in artem medicinalem Galeni* (1612) c. 62; Santorio S., *Commentaria in primam fen primi libri Canonis Avicennae* (1625)).

[130] 'Figura est vas vitreum quo facillime possumus singulis horis dimetiri temperaturam frigidam, vel calidam et perfecte scire singulis horis quantum temperatura recedat a naturali statu prius mensurato. Quod vas ab Herone in alium usum proponitur. Nos vero illud accomodavimus, et pro dignoscendua tempratura calida et frigida aeris, et omnium partium corporis, et pro dignoscendo gradu caloris febricitantium.' I quote here from a later edition of the work: S. Santorio, *Commentaria in primam fen primi libri Canonis Avicennae* (Venice 1646) c. 30-31).

[131] Santorio S., *Canonis Avicennae* c. 307-310.

air and to test whether the moon really emitted cold rays, as some astrologists claimed.[132] He was glad to show that, according to his measurements, the moon emitted warm rays just like the sun: the Paduan professor was an enemy of astrology and even subscribed to Copernican theory.

However, the degrees of heat and cold that Santorio was measuring were no novelty, but instead had a very long tradition in Aristotelian-Galenic medicine.[133] Quantification and mathematisation had played a role that tradition ever since the writings of Galen (ca. 129-200), and had been greatly developed first by Arabic-Islamic physicians, and later by Latin-Christian ones. This tradition was very important for early modern thermometry, if only because, as we just saw, it is from there that the terms 'temperature' and 'degree of heat and cold' came from.

In his works, Galen had used as a basis the Aristotelian doctrine of the four qualities (hot, cold, humid and dry) forming two pairs of opposites whose balance in a body determined its characteristics. Thus, in the form of each body, the qualities of hotness and coldness were always both present, and partly or completely balanced each other, determining the "temperature" (or "temperament") of the body as more or less hot or cold. According to Galen and his followers, the "temperature" of hotness and coldness in a body could be classified on a numerical scale of four degrees of coldness to four of hotness. Aristotelian-Galenic hotness and coldness did not refer only to tactile sensations, but also, for example, to the effects of drugs and spices, to the characteristics of illnesses and to the temperament of human beings. By the Renaissance, complex systems of classification and manipulation of degrees, among them those of hotness and coldness, had been developed.

This means that Santorio, when he used the inverted-glass-experiment to estimate the "temperature" of a patient, was operating within a very well defined theoretical framework, shared by many and known to all natural philosophers, including those who did not embrace Aristotelianism. Within Santorio's worlview, the inverted-glass-experiment found its place not as a demonstration of hitherto unknown secrets of nature, but as the operationalisation of a pre-existing theoretical model. Santorio's instrument presented a remarkable similarity to modern scientific instruments, in that not the device itself, but only its quantitative readings were suppose to be observed.

Santorio's description of temperature measurement looks deceptively similar to a modern one largely because, a already noted, the vocabulary is the same. Yet Santorio's temperature was not the modern one. For Santorio, the reference point for measuring the temperature of a body was the "temperate state" of that same body, i.e. the state in which hot and cold balanced each other exactly. Thus, in Aristotelian-Galenic terms, a healthy human body, a healthy animal and a temperate climate would all have had the same Aristotelian-Galenic "temperature": a temperate one. It is not a chance that the "temperature" of human blood remained a fixed point.

Gianfrancesco Sagredo and non-Aristotelian degrees of heat and cold

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[132] Santorio S., *Canonis Avicennae* c. 107-110.

[133] The following overview is based on: Maclean I., *Logic, signs and nature in the Renaissance* (Cambridge: 2002) 171-190; Sylla E., "Medieval quantifications of qualities: the 'Merton School'", *Archive for history of exact sciences*, 8 (1971) 9-39.

In the Bibliotheque de l'Arsenal in Paris, a manuscript is preserved, which contains a collection of mathematical marvels.[134] The author's name is Bartolomeo Telioux and the title of the collection is: 'Marvellous mathematics, wherein are to be seen the more beautful and delightful devices of pneumatics, military engines, [...]' and it is dated: Rome, 1611.[135] Collections of this kind had in the seventeenth century a fortune similar to that of the books on secrets of nature in the sixteenth one, and we shall later meet another one. One of the marvels is: 'An instrument composed by two phials with which one can know the changes in weather ('tempo') in hot or cold in degrees or minutes'.[136] The instrument is shown in a drawing as a set-up similar to, but not identical with, that of the inverted-glass-experiment. The device was made out of two long-necked glass flasks, one of which was inverted so, that its neck would fit into that of the other one. The length of the (now common) neck was graduated from one to eight. Text and drawing are somehow at odds with each other, and have been often discussed in the literature, but I shall not repeat the argument here.[137] While the details of the device are not especially relevant here, it is important to notice that already in 1611, one year before the publication of Santorio's work, an instrument to measure degrees of heat and cold in the air was presented as a mathematical curiosity and was not explicitly linked to Aristotelian-Galenic tradition. Because of this, I have translated the term 'tempo' as weather, even though at the time it might have been intended rather as "temper of the air" in an Aristotelian-Galenic sense.

Even though Telioux provides a first hint, the best evidence of how easily temperatures and degrees of heat and cold could adapt to a non-Aristotelian context can be found in the correspondence of Galileo Galilei. Once again, it is an exchange of letters in which those by Galileo himself are missing and only those of his correspondent, Giovanfrancesco Sagredo (1571-1620), remain.[138] Sagredo was a Venetian gentleman and a close friend of Galileo. During many years, he worked with the glass-makers of Murano to provide Galileo with glass instruments, especially lenses. On June, 30th 1612, i.e. a few months after Galileo had corresponded with Antonini on Drebbel's "perpetuum mobile", Sagredo wrote to him that a friend of his had been in Padua and had seen Santorio's instrument 'with which one could

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[134] The following discussion is based on: Caverni R., *Storia*, vol 1 284; Chaldecott J. A., "Bartolomeo Telioux and the early history of the thermometer", *Annals of science*, 8 (1952) 195-201 and plates X-XI; Libri G., *Historie des sciences mathématiques en Italie, depuis la Renaissance des lettres jusqu'a la fin du dix-septième siècle*, vol 4 (Paris: 1841) 471-472; Middleton W.E.K., *Thermometer* 11-12.

[135] The title page and the two pages of the manuscript relevant to the history of the thermometer are reproduced in Chaldecott J. A., "Bartolomeo Telioux" fig 2 and fig. 3, from which I quote: 'Matematica maravigliosa che sui veddono li piu vaghi et dilettevoli artifici dell pneumatico, manganaria [...] in Roma MDCXI' (Chaldecott J. A., "Bartolomeo Telioux" fig. 2).

[136] 'Instrumento composto da due fiale col quale si conosce il cambiamento del tempo in caldo o in freddo secondo gradi o minuti' Chaldecott J. A., "Bartolomeo Telioux" fig. 3.

[137] The question is sketched in Middleton W.E.K., *Thermometer* 11-12. Anyway I agree with Caverni's explanation that it responded to expansion of the air in the lower bulb, like the device described by Beeckman I., *Journal*, vol. 2 237.

[138] What little is known about Sagredo is summed up in: Galilei G., *Opere*, vol 20 *528.* Sagredo's letters on the thermometer are discussed in Caverni R., *Storia,* vol 1 275-278; Middleton W.E.K., *Thermometer* p. 6-8; Taylor F. S. "Origin" 141-142.

measure cold and heat with a compass'.[139] The friend had given a description of the device, and Sagredo's reaction had been identical to that of Antonini: he had made a copy. In fact, he made many copies of it, and even explained to Galileo how much each piece had costed him.[140]

We may speculate as to why Sagredo made so many copies of the instrument: possibly he, too, wanted to give them as valuable presents. In any case, his enthusiasm for thermometry turned out to be lasting: over the next three years, he wrote to Galileo, explaining how he had been developing and employing new forms of the device. From Sagredo's remarks, we understand that Galileo was advising him and also probably experimenting himself. Interestingly, though, almost no trace of Galileo's activity is left. Sagredo, instead, reported with enthusiasm his experiments, writing that his instruments were now so perfect, that 'the difference in temperature between one room and the other can be seen up to 100 degrees'.[141] He noted 'that in winter, air is colder than ice or snow and that now water appears colder than air [...] and similar subtleties which the Aristotelian could not explain'.[142] In 1615, he could use the instrument to compare the degrees of cold reached in that winter with those of the previous ones.[143] Although Sagredo used without problems the Aristotelian vocabulary of temperatures, temperaments and degrees, he held nothing of Aristotelian theories on the subject and speculated on the causes of the effects he saw in the instruments, asking Galileo for advice.[144] The Venetian gentleman was also the first to build himself a number of devices with the same form, but different dimensions, in such a way that he could say 'since almost three years, they work with such proportion between each other, that it is a marvel.'[145]

In conclusion, Sagredo had taken over both the instrument and the vocabulary of the Aristotelian-Galenic Santorio, while at the time questioning the relevant theories and trying to give a new philosophical meaning to the degrees shown by the device.

The Dutch weatherglass

Drebbel's "perpetuum mobile", like the set-up for the inverted-glass-experiment, could in principle detect changes both in temperature and in atmospheric pressure. The latter, as is well known today, are a rather good indicator of weather changes.[146] The discovery of air pressure is usually regarded as having taken place around 1650, although, as we have seen, the phenomenon itself had been exploited by engineers long before that. By the middle of the seventeenth century, the apparent connection between variations of the air-pressure and

[139] 'col quale se miurave il fredo et il caldo col compasso' Galilei, G., *Opere*, vol 11 350.

[140] Galilei, G., *Opere*, vol 11 350-351.

[141] 'la differenza della temperie di una stanza all'altra si vede fin 100 gradi.' Galilei, G., *Opere*, vol 11 506.

[142] 'che l'inverno sia più freda l'aria che il giaccio et la neve, che hora appari più freda l'aqua che l'aria, [...] et simili sottigliezze, alle quali i nostri Peripatetici non sanno dar nessuna rissolutione.' Galilei, G., *Opere*, vol 11 506.

[143] Galilei, G., *Opere*, vol 12 (Firenze: 1968) 140.

[144] Galilei, G., *Opere*, vol 12 157-158.

[145] 'già quasi tre anni lavorano con tanta proportione tra di loro, che è meraviglia.' Galilei, G., *Opere*, vol 12 169.

[146] On air pressure in modern meteorology and its importance for weather forecasts: Häckel H., *Meteorologie* 37-43.

weather changes and its possible causes were a subject of disputes.[147] Only in the early nineteenth century could the connection be explained in terms of a more general theory.[148]
However, even before the phenomenon of the spring of air had been conceptualized, someone had noticed the relationship between weather changes and variations of the position of water in Drebbel's "perpetuum mobile" or in the inverted glass. We have no evidence on whom that someone might have been, but we know that the discovery happened in the early seventeenth century and there are very good indications that it was made in the Netherlands.

The earliest undisputable evidence of a knowledge of the weather-forecasting capabilities of a water-in-glass instrument can be found in a document written in 1619 and preserved in the Royal Archives of Gent.[149] The document says that the wife of the engineer Ghijsbrecht de Donckere had sold to the Collegium:

> [...] a certain instrument, newly invented by her husband and called "motus perpetuus", with which it is possible to see everyday, through the rising of the water, bad weather, through the falling of the water, instead, the weather calming down, and, when the water rises very high and drops come out, that there will be storm at see.[150]

A second document tells us that later on, in 1621, Donckere was paid for his weather-forecasting "perpetuum mobile" by the city of Bruges.[151] We note that, here, the water went up with bad weather, i.e. with low air pressure. In the set-up for the inverted-glass-experiment, water would in that case instead go down, and this suggests that Donckere's device must have rather resembled the J-shaped tube which, according to de Heer and van Helmont, was sold in Liège in the 1620s.

Therefore, there is definitely the possibility that the observers of Drebbel-style perpetual motion were also aware of its weather-forecasting capabilities, a feature that would certainly have made the device even more fascinating in the eyes of its spectators. The historian Henri Michel was rightly astounded to find a reference to barometric weather forecasts so early, but other historians of science have taken this result in their stride, without highlighting its importance. Yet, noticing the water-weather connection is a highly non-trivial result, that can be achieved only under very specific conditions. First of all, a set-up similar to Drebbel's perpetual motion or to the inverted-glass experiment has to be kept undisturbed for a rather long period of time. Second, the set-up must be observed regularly, noting the changes in water level. Finally, weather conditions must also be kept under scrutiny: it is only at this point that the discovery becomes possible. Of course, the connection might still go unnoticed.
Possibly, the commercialisation of Drebbel-style perpetual motion devices contributed to the discovery of their weather-forecasting properties, since these objects were made to be set up and then left undisturbed to move by themselves. In any case, devices of this kind remained a commercial success for a long time, at least in some parts of Europe: there is ample evidence

[147] Golinski J., "Barometers" 72-77.

[148] Fierro A., *météorologie* 99-100.

[149] The following discussion is based on Bolle B., *Barometers* (Haarlem: 1978) 74-77, text printed on p. 75-76.

[150] 'zeker instrument, nieuwelijnghe bij denzelven haeren man gheinventeert, ghenaempt motus perpetuus, bij dewelcke men door het upclimmen van het water daghelicx can zien de ruijdachticheijt van het weder, metghaders door het nederdalen het verzoeten van het wedere, ende door het te zeer hooch climmen ende brobbelen de anstaende tempeesten van de see.' (Bolle B., *Barometers* 75).

[151] This second document is quoted discussed in Bolle B., *Barometers* 76 and also in Michel H., "Mouvement perpetuel" 293-294.

that, from the second half of the seventeenth century until the nineteenth century, devices of this kind were produced by glass-makers in the Netherlands and in Belgium.[152] In Dutch, the instrument became eventually known as "donderglas" ("thunderglass"), in French as "baromètre liégeois".

The end of anonymity:
Francis Bacon's 'vitrum calendare'and Giuseppe Biancani's 'thermoscopium'

In the year 1620, two works were printed, which not only described how to use the set-up for the inverted-glass-experiment to measure degrees of heat and cold, but also gave it a new name. The books were Francis Bacon's *New Organon* and Giuseppe Biancani's *The sphere of the world*.[153] In both works, for the first time, the apparatus was indicated with a specific name: Bacon called it a 'vitrum calendare', Biancani a 'thermoscopium'. As we shall see, perhaps the most determining step in the early history of the thermometer was its naming.
In his long investigation of the 'form of heat' ('forma calidi') in book 2 of the *New organon*, Francis Bacon described a device derived from the set-up for the inverted-glass-experiment and used it to demonstrate the sensibility of air to heat: "Among all bodies known to us, air is the one which most easily absorbs and emits heat, and this can best be seen in calendar glasses ('in vitris calendaris')".[154]

The term 'vitrum calendare' appeares here for the first time. The word 'calendare', as noted in a previous section, points to a connection with either weather or timekeeping and, later on, 'vitrum calendare' would be translated as 'weatherglass'.

Bacon's description differs from the many we have read only in that he advised the reader to fix the neck of the inverted glass to the mouth of the water vessel with some wax, so that it would easily remain standing. With this little addition, a temporary experimental set-up was transformed into a more or less permanent device: the 'vitrum calendare'. Bacon also suggested fixing a graduated strip of paper to the neck of the flask, to better observe how air would expand and contract. For him, the instrument measured the degrees of the air's sensitivity to heat and cold: here, too, air and its properties, and not simply heat and cold, were what was being observed in the glass. However, Bacon did not believe that the device demonstrated a particular, intrinsic activity of air, but only its sensitivity to heat. In his *History of the rare and the dense*, posthumously published in 1658, he proposed substituting water with spirit of wine, to test whether air would also react to alcohol's 'potential heat' ('calor potentialis'), like animal spirits did.[155] In his *Sylva Sylvarum* (1627), instead, he suggested using a weatherglass to test whether air would be sensitive to the cold of opium, although he doubted that the experiment would succeed.[156] These remarks show clearly how

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[152] Bolle B., *Barometers* p. 76-77; Michel H., "Le baromètre liégeois", *Physis*, 3 (1961) 203-212.

[153] Bacon F., *Neues Organon: lateinisch-deutsch*, ed. W. Krohn, 2 vols (Hamburg: 1990) 344-346; Biancani's work was originally published in 1620, but I have used the reprint of 1653: G. Biancani, Sphaera mundi, seu cosmographia (Modena, 1653) p. 54-55.

[154] 'Facillime omnium corporum apud nos et excipit et remittit calorem aer; quod optime cernitur in vitris calendaris' (Bacon F., *Neues Organon: lateinisch-deutsch*, ed. W. Krohn, vol 2 (Hamburg: 1990) 344).

[155] Bacon F., "Historia densi et rari (Rawley's version)", in: F. Bacon, *The Insturatio magna: last writings*, ed. G. Rees (Oxford: 2000) 35-169, here 106-108.

[156] Bacon F., "Sylva sylvarum", in: F. Bacon, *Works*, vol 2 331-680, here 371 (par. 74). The weatherglass is mentioned also in par. 27 (Bacon F., "Sylva Sylvarum" 348).

broad Bacon's concept of heat and cold was, much nearer to the Aristotelian-Galenic one and not yet defined through the reaction of the thermometer.

Bacon did not in any way suggest that he had invented the term "vitrum calendare". Quite the contrary, he uses it in a generic plural form which seems to imply that he was referring to well-known instruments. Therefore, we might conclude that, already in 1620, devices named "weatherglasses" were circulating in England, and it also seems probable that their sensitivity to weather changes was known, even if Bacon did not mention it.

Giuseppe Biancani (1566-1624) was a Jesuit mathematician teaching at the Gymnasium in Parma. His work was not only firmly grounded in Aristotelian tradition, but was also explicitly aimed at defending it against other worldviews.[157] In 1620, Biancani published the *Sphere of the world, or cosmography,* an anti-Copernican textbook of astronomy destined to his students. In the part of this book devoted to the movement of air, Biancani offered an image and a description of Santorio's instrument for determining degrees of heat and cold. He introduced it with these words:

> Air also has another motion, through which the same air sometimes escapes less or more or increases and diminishes its volume, and this without anything being done from the outside; physicists call this rarefaction and condensation. This is demonstrated in many experiments, and it seems fit to describe here the most beautiful and evident of them.[158]

Here followed a description of the inverted-glass-experiment, performed using coloured water. At the end, the author added:

> With the help of this instrument, which I would like to call thermoscope ('thermoscopium'), it is possible to investigate many questions relative to the nature of air. I heard that its inventor is a doctor living in Padua, called Santorio.[159]

The term 'thermoscopium' appears here for the first time and Biancani's words suggest that it was his own creation. The term was clearly modelled after "telescopium", a neologism that had been proposed less than a decade earlier, in 1611.[160] Biancani, like Bacon, linked the instrument to the possibility of investigating air, but he, too, did not find air's reaction to heat particularly remarkable. Instead, he gave the device a name describing the use Santorio had put it to: visualising heat.

Biancani had probably not read Drebbel's work, though he might well have heard of his machine. Della Porta's book on the *Transmutations of the air*, though, was known to him, because he quoted it in the paragraph just preceding that of the thermoscope.[161] Even though,

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[157] My overview of Biancan's life and work is based on: Grillo E., "Giuseppe Biancani", *Dizionario biografico degli Italiani*, 10 (1968) 33-35.

[158] 'Inest alius aeri motus, quo idem aer aliquando minor, aliquando maior evadit, seu suam auget et minuit magnitudinem, idque nullo extrinsecus additamento; hunc physici rarefactionem et condensationem appellant, quod etsi multis constet experientiis, libet tamen pulcherrimam nunc aeque ac evidentissimam afferre.' Biancani G., *Sphaera mundi* 54.

[159] 'Auxilio huius instrumenti, quod ego thermoscopium libenter appellarem, multa ad aeris naturam spectantia indagari possunt, audivi doctorem quendam medicum Patavii degentem, qui Santorius cognominatur huius esse inventorem.' Biancani G., *Sphaera mundi* 55.

[160] King H.C., *The history of the telescope* (New York: 1955 repr. 1979) 38.

[161] Biancani G., *Sphaera mundi* 54.

when discussing the thermoscope, Biancani chose to ignore the use Della Porta had made of that same device, I believe that, in writing these paragraphs, the author had Della Porta's meteors clearly in mind. First of all, he included the thermoscope in the treatment of the movement of air. Furthermore, in the paragraph following the one with the thermoscope, he refers to the question of the origin of winds, curtly stating: "The movement of winds has nothing to do with astronomy, and therefore shall have to be left to the disquisitions of the philosophers."[162]

The thermometer as a mathematical instrument

In 1622, the Jesuit college of Pont-à-Mousson published a collection of mathematical problems that had been debated during the celebrations for the day of St. Xavier and Ignatz.[163] The book was written in Latin, in a very concise and at times rather cryptic style. It was anonymous, but the Jesuit emblem on the front page made it clear that it had been written by a member of the College. Later, the book was ascribed as editor to the Jesuit mathematician Jean Leurechon (1591-1670).[164]

In the *Selectae propositiones* we find the second mention of the term 'thermoscopium' in print. The list of the subjects to be discussed in the problems of mechanics includes a demonstration of 'the temperature of air in different times and places in the thermoscope'.[165] However, the instrument does not appear anymore in the following pages.

In 1624, another collection of mathematical divertissements was printed in Pont-à-Mousson: the *Mathematical recreation composed of various entertaining and witty problems*.[166] It was in this work that the word thermometer appeared for the first time.

The *Mathematical recreation* was written in French in a very pleasant, clear and easily understandable style and it did not bear on the front page the emblem of the Jesuits. The name of the author appeared only as a signature to the dedication: 'H. van Etten'. However, this book, too, was later listed among the works edited by Leurechon. This attribution has been alternatively accepted and refuted by historians, who even raised doubts as to the actual existence of H. van Etten. Recently, historians accepted Thomas Hall's thesis that the author of the work was really a man called van Etten, whom Hall identified as a student of Leurechon.[167] Whether the editor of the *Recreation* was Leurechon himself, a student of his or whether the book had been the result of a collaboration, the work was closely linked to Jesuit

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[162] 'Ventorum agitatio nihil astronomicum sapit, ideo philosophicis disquisitionibus reliquenda est.' Biancani G., *Sphaera mundi* 55.

[163] *Selectae propositiones in tota sparsim mathematica pulcherrimae, quas in solemni festo sanctorum Ignatii et Xaverii et annivesaria collegii mussipontani celebritate literaria propugnabant mahematicarum auditores* (Pont-à-Mousson, 1622).

[164] Article: "Jean Leurechon", *Bibliothèque de la Compagnie de Jésus. Nouvelle Edition. Bibliographie*, vol 4 (Bruxelles-Pris: 1893) c. 1755-1761.

[165] 'aeriam temperiem pro diversis temporibus et locis in thermoscopio' *Selectae propositiones* 10 (mech. II).

[166] van Etten H., *Recreation mathematique composee de plusieus problemes plaisants et facetieux* (Pont-à-Mousson, 1624).

[167] Eamon W., *Secrets of nature* 420-421n29); Gronemeyer N., *Optische Magie. Zur Geschichte der visuellen Medien in der Frühen Neuzeit* (Bielefeld: 2004) 136.

circles. This fact is confirmed by the similarities between the work of 1622, which was undoubtedly of Jesuit origin, and the *Recreation* of 1624, a similarity already noted by Gustav Hellmann.[168] Even though language, style and structure of the two works are completely different, the contents of some of individual problems are very closely related to each other. For example, some problems of arithmetic are formulated in the same terms, and even use the same numbers.[169] Moreover, the list of subjects given in the introduction of the *Recreation* is almost identical to the index of the *Selectae propositiones*.[170] The 'Recreation' rapidly became an international success and was reprinted, enlarged, translated and adapted to many other languages by later authors.[171]

Books of mathematical entertainments, describing arithmetical and geometrical puzzles, mechanical devices and offering curious information of various kind, became very popular in the early seventeenth century.[172] This kind of literature was very influential on European "virtuosi", transforming mysterious experiments in natural magic into entertaining tricks. In this sense, mathematical entertainments conformed to the Jesuit idea of spreading faith through science. This might also explain why Leurechon would have had an interest to publish the book anonymously, since a Jesuit emblem on the front page might have hindered the diffusion of the work in non-catholic lands. Perhaps the best proof of how efficient this approach was, is the fact that it was in large part thanks to the success of the *Recreation* and of its later enlarged versions that the term "thermometer" became rapidly known in all Europe.

In the *Recreation*, a whole problem was devoted to the 'thermometre'.[173] The title of the section was: 'On the thermometer, or instrument to measure the degrees of heat or cold which are in the air.'[174] Two forms of the thermometer were described and also shown in a picture. The first one corresponded to the set-up of the inverted-glass-experiment. The second form was a J-shaped tube, whose lower extremity ended in an enlarged belly, which was open to the air and filled with water. According to the image, the tube was fixed onto a wooden stand with a graduated scale going from 1 to 9.[175] This was the same device as the one which in the

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[168] Hellmann G., "Erfindungsgeschichte" 14-15.

[169] For example, numbers like 244 140 625 000 000 000 000 or 611 351 562 500 00, respectively in *Selectae propositiones* 5 (arit. XI) and van Etten H., *Recreation mathematique composee de plusieus problemes plaisants et facetieux* (Pont-à-Mouson: 1626) 113-114 (87.III) (I have used the second edition of the 'Recreation') Other problems similar to each other are: *Selectae propositiones* 5 (arit. XII, XIII) and van Etten H., *Recreation* 112-114 (87.II, 87.X).

[170] Both in the *Selectae propositiones* and van Etten H., *Recreation* the lists are given in the initial pages, which are not numbered. In the *Selectae propositiones* we find: 'Arithmetica, geometrica, mechanica, cosmographica, musica, optica', in van Etten H., *Recreation*: 'Arithmetique, geometrie, mechanique, optique, musique, cosmographie.'

[171] The article: "Jean Leurechon", *Bibliothèque de la Compagnie de Jésus* lists many of the later trnaslations and adaptations.

[172] Eamon W., *Secrets of nature* 306-311; Gronemeyer N., *Optische Magie* 136-153.

[173] I shall quote from the 1626 edition of the work: van Etten H., *Recreation* 75-76 (par. 76).

[174] 'Du thermometre, ou instrument pour mesurer les degrez de chaleur ou de froidure, qui sont en l'air' (van Etten H., *Recreation* 75).

[175] The plate with the image is bound in van Etten H., *Recreation* between pages 68 and 69.

1620s was being sold to the inhabitants of Liège according to de Heer and van Helmont, and possibly also in Italy, as Marsili's letter to Galileo suggests. However, the text of the *Recreation* said nothing about tides or weather predictions. Instead, it explained in much detail that the thermometer worked because air expanded and contracted with heat, and that it could be used to learn the degree of heat or cold in the air, comparing not only one room to another, but also morning and evening, or one day to the next one. Moreover, the strength of fevers could be measured. To quantify the results, the thermometer could be provided with a scale of four or eight degrees, according either to the physicians or to the philosophers. Again, one can recognize here the heritage of Aristotelian-Galenic scales of four plus four degrees, even though there is absolutely no mention of the ancient philosophers in the text.

In describing the thermometer and its use, the author of the *Recreation* was not simply demonstrating a curiosity, but was offering an explanation for the behaviour of various devices that were circulating in that period, purportedly demonstrating the activity of air. The author of the book defined all such devices as "thermometers", and thus assimilated them to mathematical instruments, i.e. tools whose working principles were perfectly known, and which helped measure various physical quantities. In 1629, yet another Jesuit, Niccolò Cabeo (1585-1650) explicitly characterized Drebbel's "perpetuum mobile" as a "thermoscopium", stating that the device maintained its utility even though now its secret had been discovered.[176]

In conclusion, even though the evidence is hardly cogent, a plausible case can be made that the origin of the word "thermometer" might be sought in Jesuit circles, and in particular among Jesuit mathematicians. Almost immediately, however, both the word "thermometer" and the Aristotelian terms "temperature" and "degree of heat and cold" became part of a hybrid vocabulary shared by philosophers of all schools of thought.

Pneumatic versus mechanic technology?

The importance of the naming of the thermometer can hardly be underestimated. "Thermoscope" and "thermometer" were much more than new labels for pre-existing instruments: they were in a sense definitions, because they stated the function of the object they indicated. The thermometer was an instrument to measure heat, and all its other features were thus effectively put out of focus, in particular the activity of the air. Seen through this filter, the inverted-glass-experiment became the earliest form of the thermometer and, within a few decades, the same name could be applied to the thermometers of the Accademia del Cimento, which measured heat through the expansion and contraction of spirit-of-wine. Unlike Biancani's and van Etten's thermometers, these instruments did not - could not - demonstrate the activity of the air, and neither could they help predict the weather.

However, as the material discussed should have shown, in the 1630s there was no clear-cut distinction between weatherglass, thermometer and "perpetuum mobile". All these aspects were perceived by each observer in the same instrument, even though he might eventually chose to concentrate only on those features that most appealed to his own worldview. Bacon spoke of measuring the air's sensitivity to heat, but used the term "weatherglass". Sagredo used the vocabulary of Aristotelianism to dispute its theories. Biancani spoke of measuring Aristotelian temperatures like Santorio had done, but probably had Della Porta's discussion of the origin of wind in his mind. The author of the *Recreation* described how entertaining the instrument could be, and astutely left its interpretation to his readers.

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[176] Drake-Brockman J., "perpetuum mobile" 14-142.

It is important to stress once again that all features of the weatherglass/thermometer were in principle well worth attention. The measure of heat and cold was certainly a good reason to regard thermometers as interesting from the natural philosophical point of view, but also the question of why the air reacted to heat and cold, as well as its capability of responding to weather changes were of great potential interest. Because of the many different philosophical viewpoints which not only competed, but often also complemented each other in early seventeenth-century Europe, there was no clear-cut distinction between weatherglass and thermometer. Moreover, there is no reason to believe that such a distinction established itself shortly afterward.[177] We have already seen how Drebbel's perpetual motion continued fascinating audiences for many decades, and how Dutch weatherglasses, whose main function was to help predict weather, were produced and perfected from the seventeenth century onward. In 1636, when the *Recreation* was translated into Latin, the term 'instrumentum Drebelianum' was added to the name thermometer and, as we have already seen, the name of Drebbel remained linked to the thermometer at least until the late eighteenth century.[178] The story of the thermometer has often been told, that of the weatherglass has rather been forgotten. However, in the 1630s, the latter was probably more popular than the former, at least in some countries.

In the 1630s, weatherglasses were being made and sold also in England. In his *Mysteries of nature and art* (1634), a collection similar to the *Recreations* but more instrument-oriented, the instrument-maker John Bate discussed more than seven variants of the weatherglass.[179] He also explained at length its weather-forecasting properties:

> Albeit the formes of weather-glasses are divers, according to the fancy of the artist, yet the use of all is one and the same: to wit, to demonstrate the state, and temper of the season, whether hot or cold, and also to foreshew the change and alteration thereof.
> 1. Note therefore, that the nature and property of the water in all the glasses that have no vent holes at the top, is, to ascend with cold, and descend with heat. But in them that have vents, it descendeth as much as it ascendeth in these.
> 2. The sudden falling of the water is an evident token of rayne.
> 3. The continuance of the water at any one degree, is a certaine token that the weather will continue at that stay it is then at, whether it be fayre, or foule, frost or snow. But when the water either riseth or falleth, the weather will then presently change.
> 4. The uncertain motion of the water is a signe of fickle weather.
> [...] These rules are all certain and true: now you may according to your owne observation frame other rules, whereby you may foretell the change of the weather the water being at any one degree whatsoever. [180]

It was exactly in these years that Robert Fludd chose the weatherglass to represent all aspects of his cosmology.[181] Fludd mentioned the weatherglass first in 1617, but it was especially in

[177] In fact, there is evidence to the contrary: Castle T., *The female thermometer. Eighteenth-century culture and the invention of the uncanny* (New York-Oxford: 1995) 21-43.

[178] Wohlwill E., "Erfindung" 163-164.

[179] Bate J., *The mysteries of nature and art* (London: 1634) 28-39. On Bate and his work, see Eamon W., *Secrets of nature* 307.

[180] Bate J., *Mysteries* 38-39.

the *Integrum morborum mysterium* (1631) and in the *Philosophia Mosayca* (1638) that the instrument became, as Allen Debus noted, 'a key to two worlds', i.e. microcosmos and macrocosmos. In Fludd's cosmology, meteors, especially winds, played a central role, and his theory of meteors is very similar to those of Drebbel and Della Porta. The heat of the sun, which was of divine origin, acted on the element air, infusing it with the spirit of life. This spirit was spread by air to all living creatures. Fludd considered the four winds as the instrument with which God acted on the sublunary world.[182] In this context, the weatherglass not only demonstrated the origin of winds, but also embodied all correspondences between microcosmos and macrocosmos in a way which it would be impossible to summarize here.
Significantly, Fludd reproduced in his *Integrum morborum mysterium* Drebbel's image of the inverted-glass-experiment.[183]

In the *Philosophia moysaica*, translated into English in 1659, Fludd explained that he had chosen the weatherglass as a visual demonstration of his docrines because it was a well-known device:

> I will make therefore election of such demonstrative machine for my purpose as is vulgarly known amongst us, hereby my intentions may be more easily understood of every man.[184]

Fludd explained the principles according to which the weatherglass functioned as contraction 'when the included aire is animated by the externall cold' and expansion 'if the included spirit be excited by any externall heat'.[185] He also gave instructions on how to use the weatherglass to predict weather, and they were similar to those printed by John Bate.[186] Fludd's reflections were an original development of previous Paracelsian theories, which he supported through new discoveries not only in meteorology, but also concerning the relationship between blood circulation and respiration as well as between air and combustion.

In his work, he fully exploited the explanative potential of the weatherglass - in fact, well beyond its limits - and gave great relevance both to alchemy and to pneumatics, filling the pages of the *Integrum morborum mysterium* with images and descriptions of Heronian instruments.[187]

By contrast, Descartes never even mentioned in his work weatherglasses or thermometers and instead made large use of mechanical automata in his explanations.[188] Once again we see how, in the early seventeenth century, each philosophy chose its own, favourite technology.

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[181] The following overview is based on: Debus A.G., "Key to two worlds: Robert Fludd's weather-glass", *Annali dell'istituto e museo di storia della scienza di Firenze*, 7 (1982) 109-143; Debus A.G., *Chemical philosophy*, vol 2 205-293; Debus A.G., *English Paracelsians* 101-127.

[182] Debus A.G., "Key to two world" 126-127.

[183] Fludd R., *Integrum morborum mysterium: sive medicinae catholicae tomi primi tractatus secundus* (Frankfurt: 1631) 462.

[184] I quote from the English translation: Fludd R., *Mosaicall philosophy grounded upon the essential truth, or eternal sapience* (London: 1659) 2.

[185] Fludd R., *Mosaicall philosophy* 6.

[186] Fludd R., *Mosaicall philosophy* 6-7.

[187] See for example: Fludd R., *Integrum morborum mysterium* 420-476.

[188] I base this statement on the fact that no quote by Descartes appears in histories of the thermometer, and it is highly improrbable that it would have escaped notice.

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