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Re-entangling the Thermometer: Cornelis Drebbel's Description of his Self-regulating Oven, the Regiment of Fire, and the Early History of Temperature

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Abstract
A new, illustrated source, "Drebbel's Description of his Circulating Oven," sheds light on the thermostatic oven of Cornelis Drebbel (1572-1633), a Dutch alchemist, engineer, and philosopher active in Holland, Zeeland, London and Prague. The "Description" survives in two German copies. It describes two new inventions, a "Judicium" (which we might call a thermometer) and a "Regimen" (which we might call a feedback control mechanism). It thus engages longstanding debates concerning the invention of the thermometer. More fundamentally, it engages the relationship of artisanality and philosophy. The "Description" highlights the entangled origins of both instruments, which emerged through combined concerns of alchemy, engineering, philosophy, and natural magic. In the early seventeenth century, the term "thermometer" indicated an object with a more expansive role than it later would. The later emergence of a distinct scientific instrument industry, separating previously entangled roles, has colored subsequent views of such instruments and their makers.

Keywords
thermometer, Cornelis Drebbel, feedback control, instrument

1. Introduction: The Self-regulating Oven between Theory and Practice

Much ink has been spilled over the early history of the thermometer. A never before studied text describing the self-regulating oven of Cornelis Drebbel (1572-1633) has the potential to shed new light on that history. Cornelis Drebbel of Alkmaar in North Holland trained as an engraver with his brother-in-law, the famed artist Hendrick Goltzius. He began experimenting with alchemy, engineering and a number of new devices at a young age. He obtained patents for a number of inventions, including for

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"a chimney with a good draught." At the age of thirty-two, he left the Netherlands and sought to make his fortune in England, with a natural philosophical text under his belt. He succeeded in gaining favor in James I's court, and except for a brief sojourn in Prague of Rudolf II, he spent the remainder of his life in English courtly employ. There he developed both spectacular and useful arts which might intrigue and serve his patrons, such as catoptric displays, an art of artificial cold production, his celebrated submarine, torpedoes and optical instruments. He eventually gained a position as a military engineer within the Ordnance Office, where a long-term associate and fellow alchemist, John Heydon was Lieutenant. While Drebbel remained in England, his associates and sons-in-laws, the Küfflers of Cologne, marketed his various products on the continent, including microscopes and telescopes.[1]

Drebbel's devices included two which deployed changes in heat, cold and (what we would now call) air pressure in order to regulate movement: the "perpetual motion machine" he first presented in the court of King James I in 1607 and a self-regulating oven developed in the 1620's. Drebbel had illustrated the basic principles according to which these devices worked within his printed natural philosophical work, *On the Nature of the Elements*. There, a contrived demonstration showing Drebbel's theory of winds appeared as the only figure other than Drebbel's own portrait.[2] It was this figure, in addition to his self-regulating oven, which has made Drebbel a

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[1] It is a pleasure to acknowledge Joachim Telle, Leigh Penman, Rienk Vermij and the anonymous reviewers. Telle informed me of the Hamburg manuscript, and Penman, Vermij, and the reviewers offered very helpful comments. Thanks also to Dr. Hans-Walter Stork and the Staats- und Universitätsbibliothek Hamburg for permission to publish images from the manuscript. This research was in part funded by a Herzog-Ernst Fellowship of the Fritz Thyssen Foundation, Gotha-Erfurt. For Drebbel's life, see F. M. Jaeger, *Cornelis Drebbel en zijne tijdgenooten* (Groningen: Noordhoff, 1922), Gerrit Tierie, *Cornelis Drebbel (1572-1633)* (Amsterdam: Paris, 1932), L. E. Harris, *The Two Netherlanders: Humphrey Bradley and Cornelis Drebbel* (Leiden: Brill, 1961), and Vera Keller, *Cornelis Drebbel (1573-1633): Fame and the Making of Modernity* (Ph.D. diss., Princeton, 2008). For Drebbel's patent in the Netherlands, see G. Doorman, *Patents for Inventions in the Netherlands during the 16th, 17th and 18th centuries* (The Hague: Nijhoff, 1942), p. 103.

[2] Cornelis Drebbel, *Ein kurtzer Tractat von der Natur der Elementen Und wie sie den Windt/Regen blitz und Donner verursachen und wozu sie nutzen* (Leiden: von Haesten, 1608), [A8]. Drebbel referred to the figure repeatedly in his text, since he argued, if considered carefully by the reader, it would allow the reader to understand his theories better than he could from words. For more on the contrived demonstration, see Vera Keller, "How to Become a Seventeenth-Century Natural Philosopher: The Case of Cornelis Drebbel," *Silent Messengers: The Circulation of Material Objects of Knowledge in the Early Modern Low Countries*, edited by Sven Dupré, Christoph Lüthy (Berlin: LIT Verlag, 2011), pp. 125-151. The figure was also copied in later manuscripts, as in Cornelis Drebbel, *Ein kurzer Tractat von der*

candidate in debates concerning the invention of the thermometer since 1636.[3] The term thermometer was first coined in a 1624 work (variously ascribed to Jean Leurechon or Hendrick van Etten) of mathematical recreations.[4] In a 1636 Latin translation of the French text produced by the Cologne translator Caspar Ens, the instrument which had previously appeared simply as a "thermomètre," gained as well the description "Instrumentum Drebilianum."[5] This interpellation by Ens has typically been seen as the moment when the myth that Drebbel invented the thermometer entered the literature.[6] As we shall see, the matter cannot be decided quite so simply. The difficulty in identifying the inventor of the thermometer lies in a much greater issue – the difficulty in identifying the thermometer in particular and a scientific instrument in general in an era when such categories were either non-existent or in flux.[7]

Natur der Elementen/ und wie sie den Wind/Regen/ Blitz unnd Donner verursachen, Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 715.

3 For studies of Drebbel's thermometers, see inter alia, Emil Wohlwill, "Zur Geschichte der Erfindung und Verbreitung des Thermometers," *Poggendorff's Annalen*, 1865, *124*:163-178; Fritz Burckhardt, *Die Erfindung des Thermometers und seine Gestaltung im XVII. Jahrhundert* (Basel: Schultz, 1867); Henry Carrington Bolton, *Evolution of the thermometer, 1592-1743* (Easton, PA: Chemical Publishing, 1900); Emil Wohlwill, "Neue Beiträge zur Vorgeschichte des Thermometers," *Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften*, 1902, *1*:143-158; Wilhelm Schmidt, "Zur Geschichte des Thermoskops," *Zeitschrift für Mathematik und Physik*, 1898, *8*:165; H. A. Naber, "Cornelis Jacobsz Drebbel," *Oud Holland*, 1904, *22*:195–237, p. 201; F. M. Jaeger, *Cornelis Drebbel* (cit. note 1), p. 138; Gerrit Tierie, *Cornelis Drebbel* (cit. note 1), pp. 4, 92; F. W. Gibbs, "The Furnaces and Thermometers of Cornelis Drebbel," *Annals of Science*, 1948, *6:1*:32-43; Marie Boas, "Hero's Pneumatica: A Study of Its Transmission and Influence," *Isis*, 1949, *40:1*:38-48, p. 45; Martin Barnett, "The Development of Thermometry and the Temperature Concept," *Osiris*, 1956, *12*:269-341; W. E. Knowles Middleton, *A History of the Thermometer and Its Use in Meteorology* (Baltimore: Johns Hopkins Press, 1966), pp. 14-23; Kirstine Bjerrum Meyer, *Die Entwickelung Des Temperaturbegriffs Im Laufe Der Zeiten* (Braunschweig: Vieweg, 1981), p. 28; Arianna Borrelli, "The Weather Glass and its Observers in the Early Seventeenth Century," in *Philosophies of Technology: Francis Bacon and his Contemporaries*, edited by Claus Zittel, Gisela Engel, Nicole C. Karafyllis and Romano Nanni (Leiden, Brill, 2008), pp. 67-132; and Robin Buning, "An Unknown Letter from Henricus Reneri to Constantijn Huygens on the Thermometer and the Camera Obscura," *Lias*, 2010, *37:1*:89-106.

4 I was unable to consult the rare 1624 first edition and cite here the second 1626 edition. Jean Leurechon or Hendrick van Etten, *La récréation mathématiques, ou Entretien facétieux sur plusieurs plaisants problèmes, en fait d'arithmétique, de géométrie, arithmétique, mécanique, optique, et autres parties de la science belle* (Pont a mousson: N.A., 1626), 77.

5 Caspar Ens, *Thaumaturgus mathematicus* (Köln: Münich, 1636), pp. 125-8.

6 Beginning with Wohlwill, "Zur Geschichte," (cit. note 3), p. 164; Burckhardt, *Die Erfindung* (cit. note 3), p. 7; and Naber, "Cornelis Jacobszoon Drebbel," (cit. note 3), p. 225.

7 For the problem of the identity of an instrument, see Deborah Jean Warner, "What Is a Scientific Instrument, When Did It Become One, and Why?" *British Journal for the History of*

Since the oven employed what later came to be called a thermometer to both measure and regulate heat, it has become a subject of interest to the early history of thermometry. It also enjoys today a retrospective and perhaps unwarranted fame as an ancestor of modern feedback control, with repercussions for the future of steam engine design.[8] The two versions of the work translated and discussed here, offer a much richer account of the oven's early conceptualization than does the currently known source for the design of Drebbel's oven (found in the recipe book of Drebbel's grandson, Augustus Küffler, also known as Kuffeler).[9]

The text survives in two late seventeenth-century German translations (a transcription, translation and images are included in the Appendix). These are entitled "Drebbel's Description of his Circulating Oven communicated by D. Reger (Drebbelii Beschreibung Seiners Circulir Ofens communic[ata] a D. Reger)" and "Here follows the full description of Drebbel's secret oven, and how it may be composed from many parts, all of which are indicated in the figure with numbers and letters (Nun folget die volle Beschreibung des Drebbelii geheimen Ofen, und wie er von vielen stücken componiret werde, wie aller in dem schemate der Augenschein No. und Buchstaben mit mehern weisen)."[10] The manuscript in Hamburg includes figures showing various parts of the oven's mechanism, including the scale of degrees (see Figs. 1 and 2), with letters keyed to the text. Short of discovering a holograph manuscript, it is always possible that the text is not Drebbel's own. The content, style, and provenances of the manuscripts offer good reasons for accepting the ascription to Drebbel, however. If accepted as representing Drebbel's account, these manuscripts would disprove many of the current claims about Drebbel's thermometers, such as that he did not use a scale of degrees or that he did not offer any explanations for his devices.

Science, 1990, *23*: 83-93; Robert Bud, Deborah Jean Warner, and Stephen Johnston (eds.), *Instruments of Science: An Historical Encyclopedia* (London: Science Museum, 1998); Albert van Helden and Thomas L. Hankins (eds.), *Instruments* (*Osiris*, new series, 9) (Chicago: University of Chicago Press, 1994); Liba Taub, "Introduction: Reengaging with Instruments," *Isis* (Focus), 2011, *102*:689-696; and Jean-François Gauvin, "Instruments of Knowledge," in *The Oxford Handbook of Philosophy in Early Modern Europe*, edited by D. M. Clarke, C. Wilson (Oxford, Oxford University Press, 2011).

[8] Bernhard Dotzler, *Papiermaschinen: Versuch über Communication & Control in Literature und Technik* (Berlin: Akademie Verlag, 1996).

[9] Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 652, 430-435. *A Very Good Collection of Approved Receipts of Chymical operations collected by Augustus Kuffeler and Charles Ferrers Phylchimist*, Cambridge University Library MS Ll.5.8.

[10] Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 652, 430-435 and Thuringian State Archive, Geheimes Archiv, E XI, Nr. 70, 80-81.

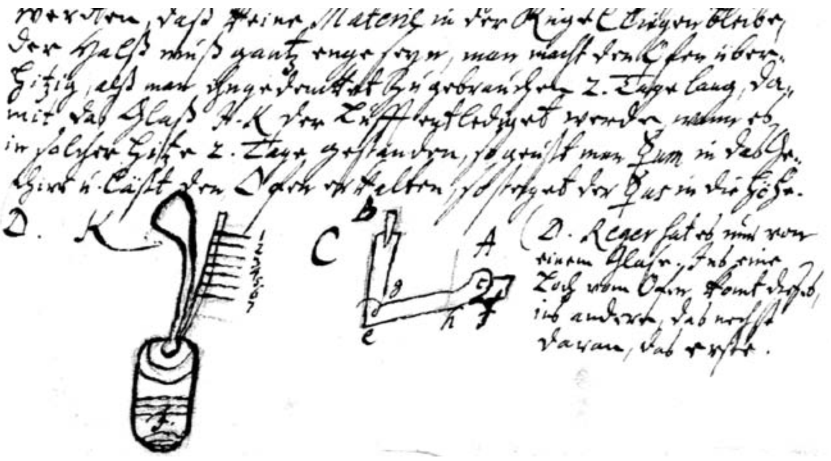

Figure 1. Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 652, 434r.

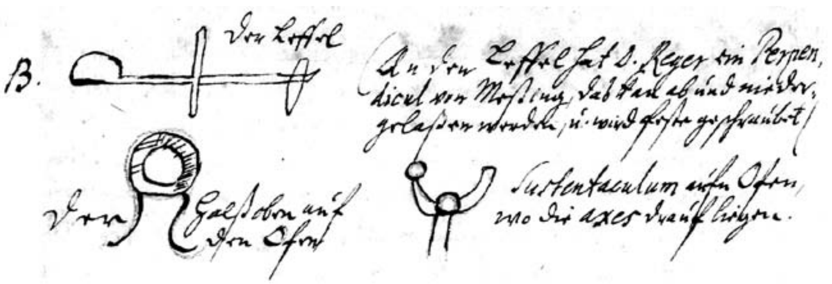

Figure 2. Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 652, 434v.

More fundamentally, the text illuminates the relationship between craft and philosophy, between instruments of thought and of practice, in the development of the thermometry concept and conceptual shifts in meteorology and natural philosophy more broadly. Various parts of the oven, including the part which measured degrees of heat (the "*Vas judicatorium*") as well as the part which controlled access of air to the fire (the *"Regimen"*) are described as instruments ("*Instrumenten*"). The explanations offered for the oven's workings in the *Description* connect these various instruments to philosophical ideas. Such explanations allow us further to situate the source for Drebbel's ideas within the works of his hands and the material culture of his machinery, where he repeatedly claimed they originated.[11]

The difficulty in distinguishing between various kinds of instruments in the early seventeenth century raises a larger issue concerning the sources of philosophical concepts and experimental agendas. In some accounts, the history of the conceptual shift from temperament to temperature over the course of the century began with a shift from Galenic medicine and Aristotelian natural philosophy to mechanical philosophy.[12] According to those narratives, mechanical philosophers necessitated empiricism, and empiricism necessitated the development of metric instruments. Philosophers had ideas, and those ideas produced the objects made by craftsmen. Vice versa, in more materially determinist accounts in the history of science, pressures from the world of craft bring innovations from the world of craft to the world of philosophy.[13] Cornelis Drebbel, however, was both an artisan and a philosopher whose career fits neither of these "from/to" models.[14]

The role of artisans, instruments and material culture in the history of science has received a great deal of attention.[15] However, we still lack a language for discussing the fusion of a wide array of practices and theories

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[11] See Cornelis Drebbel, *Wondervont* (Alkmaar: Jaacob de Meester, 1607), [Bv], "Want verclare door den levendigen Godt/ dat noch die schriften van de Ouden/ noch eenighen Mensch my de minste hulp hier in ghedaen heeft: maer heb dit alleen ghevonden/ door gestadich opmercken/ in't ondersoecken van de Elementen" and Cornelis Drebbel, *Ein kurtzer Tractat* (cit. note 2), p. [Bvi], "Dieses lieber Bruder habe ich von der natur geschriben wie ich solches mit der handt befunden."

[12] Everett Mendelsohn, *Heat and Life: The Development of the Theory of Animal Heat* (Cambridge: Harvard University Press, 1964), and Hasok Chang, *Inventing Temperature: Measurement and Scientific Progress* (Oxford: Oxford University Press, 2004).

[13] As in Gideon Freudenthal and Peter McLaughlin (eds. and trans.), *The Social and Economic Roots of the Scientific Revolution: Texts by Boris Hessen and Henryk Grossman* (Boston: Springer, 2009) and Edgar Zilsel, *The Social Origins of Modern Science*, edited by Diederick Raven, Wolfgang Krohn, and Robert S. Cohen (Dordrecht: Kluwer, 2000).

[14] I similarly criticize the "from/to" historiographic model in "The Authority of Practice in the Alchemy of Sir John Heydon (1588-1653)," *Ambix, Journal of the Society for the History of Alchemy and Chemistry*, 2012, *59*:197–217.

[15] Some recent approaches to artisanal philosophy can be found in Pamela Long, *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins University Press, 2001); Pamela Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004); Bruce Moran, *Andreas Libavius and the Transformation of Alchemy: Separating Chemical Cultures with Polemical Fire* (Sagamore Beach, MA: Watson, 2007); and Ursula Klein, "The Laboratory Challenge: Some Revisions of the Standard View of Early Modern Experimentation," *Isis* (Focus), 2008, *99*: 769-782.

such as natural magic, alchemy, natural philosophy, natural history, craft, projecting, engineering and court culture.[16] In order to fully account for the work of figures who were not solely artisans, engineers, or philosophers, we need a new language. We might turn to another historical vocabulary developed in order to account for the diverse sources of modern categories (in this case, temperature, thermometer, or scientific history). "Entangled history" is a term drawn from German-language history, more traditionally used to discuss the development of nationalist categories which tend to occlude their diverse and interconnected sources. Entangled history analyses how "intercourse and exchange contributed to the production of the units we still operate with today." The theoretical and practical sources for the thermometer and scientific instruments more generally need to be re-entangled.[17] In this case, such exchange might not only be between types of persons (for example, between artisans and philosophers), but between practices and sources of authority within a single career.

2. Provenance

Joachim Telle kindly brought to my attention the existence of one version of this manuscript in the Staats- und Universitätsbibliothek Hamburg.[18] The Hamburg manuscript is entitled "Drebbel's description of his circulating oven" and, although a late seventeenth-century copy in translation, it is written as a first-person narrative. It is to be found in Hamburg Alchim. 652, a 463-page alchemical collection gathered by Benedictus Nicholaus

[16] Several contributors to the *Isis* Focus section on alchemy broached the topic of both practical and theoretical eclecticism, such as Bruce T. Moran, "Introduction," *Isis* (Focus), 2011, *102*: 300-304 and Tara Nummedal, "Words and Works in the History of Alchemy," *Isis* (Focus), 2011, *102*:330-337. Andrea Bernadoni has studied the combined roles of alchemy with engineering and other interests in the careers of Leonardo and Biringuccio; see Andrea Bernardoni, "Leonardo and the chemical arts," *Nuncius*, 2011, *27*:11-55 and Andrea Bernardoni, *La conoscenza del fare: ingegneria, arte, scienza nel De la pirotechnia di Vannoccio Biringuccio* (Roma: L'Erma di Bretschneider, 2011).

[17] Sebastian Conrad, "Circulation, 'National Work,' and Identity. Debates about the Mobility of Work in Germany and Japan, 1890-1914," in *Entangled Histories and Negotiated Universals. Centers and Peripheries in a Changing World*, edited by Wolf Lepenies (Frankfurt a.M.: Campus, 2003), pp. 260-280, 276.

[18] "Drebbelii Beschreibung Seiners Circulir Ofens communic[ata] a D. Reger," Staats- und Universitätsbibliothek Hamburg, Cod. alchim. 652, 430-435. See Julian Paulus, "The Collection of Alchemical Books and Manuscripts in Hamburg", in *Alchemy revisited: Proceedings of the International Conference on the History of Alchemy at the University of Groningen, 17-19 April 1989*, edited by Z. R. W. M. von Martels (Leiden: Brill, 1990), pp. 245-249.

Petraeus sometime after 1673.[19] Petraeus is best known as the editor of several alchemical collections, and in particular, an over one-hundred-page "Critique" of alchemical literature prefacing his edition of Basilius Valentinus, which first appeared in Hamburg in 1717.[20] He also published and defended a medical dissertation in Utrecht in 1699.[21] The Hamburg manuscript is in German and is described as "communicated by D. Reger." Reger might be Georg Ernst Aurelius Reger, a German Behmenist physician who flourished in the Hague in the late seventeenth century, but who published his works in German both in the Netherlands and in German lands.[22]

A second version can be found in the Thuringian State Archive in Gotha. The Gotha manuscript, copied in the hand of Duke Friedrich I of Saxe-Gotha-Altenburg himself (according to Oliver Humberg), is written in the second person and is characterized as the "full description of Drebbel's secret Oven."[23] Although in the hand of the Duke, the manuscript is signed "N." "N" also discussed what Johann Moriaen of Muÿden had previously noted down ("hat hierbeÿ notiret") on the manuscript of the *Description*.

Friedrich I employed a wide network of alchemical agents around Europe, including in the Netherlands and Hamburg, and he may have obtained this manuscript through any one of them. His father, Duke Ernst I, was also in correspondence with figures such as Henry Oldenburg and John Dury and proposed an exchange of information and curiosities with

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[19] Julian Paulus, Ms. of the Katalogs der alchemistischen Handschriften der Staats- und Universitätsbibliothek Hamburg, from email communication with Dr. Hans-Walter Stork on March 11, 2011.

[20] B. N. Petraeus (ed.), *Drey Vortreffliche und noch nie im Druck gewesene Chymische Bücher* (Hamburg: Naumann, 1670) and Basilius Valentinus, *Basilius Innovatus* (Hamburg: Samuel Heyl, 1717).

[21] B. N. Petraeus, *Disputatio medico-chymica inauguralis de natura metallorum nonnullisque eorum artefactis* (Utrecht: G. vande Water, 1699).

[22] On Reger, see John Ferguson, *Bibliotheca Chemica* (Glasgow: Maclehose, 1906), p. 32. Reger's first publication was *Gründlicher Bericht Auff einige Fragen/ Bekräfftiget durch drey übereinstimmende Zeugen/ als Der Heiligen Schrifft/ Dem Buch der Natur/ und Dem Buch der Menschheit* (Hamburg: Wolff, 1683). It appeared with a catalogue of the manuscripts of the Holsatian alchemist active in Amsterdam, Ericus Pfeffer. Reger next published *Das Buch Amor proximi geflossen aus dem Öhl der göttlichen Barmhertzickeit* (The Hague: P. Hagen, 1686) anonymously. In the *Nosce te Ipsum physicum-medicum* (Nürnberg: Wolffgang Moritz Endter, 1705), p. 216, Reger referred to his previous authorship of the *Gründlicher Bericht* and *Amor Proximi*. He signed the work "Ryswyk ausser dem Haag in Musaeo meo, Ernestus Reger."

[23] Thuringian State Archive, Geheimes Archiv, E XI, Nr. 70, 80-81. Oliver Humberg, *Der alchemistische Nachlaß Friedrichs I. von Sachsen-Gotha-Altenburg* (Elberfeld: By the author, 2005), p. 14.

them. He particularly enquired about another invention of Drebbel's which had passed to Drebbel's son-in-law (Dr. Johann Sibbert Küffler) – the torpedo. As Henry Oldenburg wrote to the London-based "intelligencer," Samuel Hartlib, the Duke had heard of "Dr.Küfflers fire-machine . . . thought to have aurum fulminans in it, and to consist chiefly in the art of seasonably kindling it; but desired much to heare more of it by me, offering himself to communicate other things to us, yt might not be unprofitable."[24]

The description of the oven may have been the subject of one such communication. The earliest description of Drebbel's self-regulating furnace can be found in Nicholas-Claude Fabri de Peiresc's interview with Drebbel's sons-in-law, the Küfflers, in Paris in 1624.[25] Drebbel's children and in-laws then sold a fourteen-year patent for his ovens in 1634, the year after Drebbel's death, to two of Drebbel's associates from the Ordnance Office. The patent describes ovens whose "heate may . . . be increased, moderated or abated to any proporcion or degree that shalbee held most fitt or requisit . . ."[26] During the 1640's and 1650's, the oven became the subject of widespread interest and communication. It was re-created in England, New England, France, the Netherlands, and Germany, by figures such as Johann Moriaen, Benjamin Worsley, Christopher Wren, and Johann Joachim Becher.[27]

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[24] Henry Oldenburg, *The Correspondence of Henry Oldenburg, Volume I, 1641-1662*, edited by A. Rupert Hall, Marie Boas Hall and Eberhard Reichmann (Madison: University of Wisconsin Press, 1965), pp. 179-180.

[25] Nicholas-Claude Fabri de Peiresc, "Relation de ce que j'ai appris de la vie et des inventions de Corneille Drebbel," Bibliothèque Municipale Inguimbertine, Ms. 1776.

[26] Hildebrand Prusen and Howard Strachy, A.D. 1634, No. 75, "Stoves or Furnaces for Drying and Heating," in Bennett Woodcroft (ed.), *Appendix to Reference Index of Patents of Invention*, (London: Patent office, 1855), p. 16. For more on the use of the ovens in Heydon's orbit, see Keller, "The Authority of Practice," (cit. note 14). Further research might reveal a connection between the manuscripts reproduced here and attempts by individuals to claim patents to the oven's design in the 1650's.

[27] For Christopher Wren's reproduction of Drebbel's perpetual motion and his oven, see Balthasar de Monçonys, *Iovrnal des voyages de Monsievr de Monçonys*, 2 vols., Vol. II (Lyons: Horace Boissat & George Remevs, 1666), p. 54. In Volume I (1665), pp. 41-42, de Monçonys also mentioned visiting a certain M. Merendiere in La Rochelle in 1645, who had "l'invention de donner le feu au degré qu'il veut, & de l'y conserver." Hartlib recorded in 1656 that Worsely purchased the secret of the oven from the Küfflers. Samuel Hartlib and the University of Sheffield, "Ephemerides," in *The Hartlib Papers* (cit. note 27), 29/5/100B. For New England, see Bruce White and Walter Woodward, " 'A Most Exquisite Fellow' — William White and an Atlantic World Perspective on the Seventeenth-Century Chymical Furnace," *Ambix*, 2007, *54:3*:285-298. Johann Joachim Becher claimed to have been the first to develop a thermoscopically controlled motion in 1656; see Johann Joachim Becher, *Theoria et experientia de nova temporis dimitiendi ratione et accurata horologiorum*

Johann Moriaen (ca. 1591-1668), a Reformed minister, alchemist, and projector, enjoyed access to a widespread network of religious and scientific reformers, including Samuel Hartlib, Isaac Beeckman, and the Küfflers, whom he knew from his time serving as a minister in Cologne. He then settled in Amsterdam and later in Muiden (a small town not far from Amsterdam). There he reproduced several of Drebbel's inventions, including his ovens, with the help of Drebbel's son-in-law Johann Sibbert Küffler. In a 1652 letter to Samuel Hartlib, he discussed his knowledge of Drebbel's oven and his attempts to reproduce it with a partner.[28] As John Young has discussed, taking out patents upon inventions was not a viable strategy during the Interregnum. Nevertheless, Moriaen hoped to receive assurances from the state for his reproduction of the oven together with Küffler, who returned to England in 1656 for that purpose.[29] They failed to receive state support, but Küffler remained in England and continued producing the ovens, as John Evelyn witnessed in 1666.[30]

Moriaen also had the ovens built in Amsterdam. The Dane Olaus Borch, visiting Moriaen in 1662, observed the "furnace of Drebbel made through the application of Mercury in a bent glass, which contracts and expands with heat."[31] Hartlib also described a group of manuscripts left in Amsterdam which included accounts of twelve Drebbelian inventions, including his ovens. According to Hartlib, "none of the philosophers other than Drebbel have until now written expressly about the nature of fire" as in his manuscripts left in Amsterdam.[32]

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constructione (London: Mark Pardoe, 1680), pp. 15-16: "Cornelius Drebbel Alcmariensis primus Thermoscopii inventor exitisse perhibetur . . . . Post illum quod sciam nemo manum applicationi ad motus Mechanicos Thermoscopiis adhibuit, nisi quod ego anno 1656." See also Johann Joachim Becher, *Närrische Weißheit und Weise Narrheit* (Frankfurt a. M.: Zubrod, 1682), pp. 85-86.

[28] On Moriaen, see J. T. Young, *Faith, Medical Alchemy and Natural Philosophy: Johann Moriaen, Reformed Intelligencer, and the Hartlib Circle* (Brookfield, VT: Ashgate, 1998) and Ruud Lambour, "De Alchemistische wereld van Galenus Abrahamsz. (1622–1706)," *Doopsgezinde Bijdragen*, 2005, *31*:92-168. A 1652 letter from Johann Moriaen discusses his efforts to reproduce "Drebbelii Kunst-Ofen," *The Hartlib Papers* (cit. note 27), 63/14/20A.

[29] Young, *Faith* (cit. note 28), pp. 54-6.

[30] *ibid.*

[31] Olaus Borrichius, *Itinerarium 1660-1665*, 4 vols., Vol. II (London: Brill, 1983), p. 165. "Drebbelii furnus fit per adhibitionem Mercurii in vitro incurvato, qui contrahitur et extenditur, pro ut calor agit." See also Moriaen's discussion of Drebbel in Isaac Beeckman, *Journal tenu par Isaac Beeckman*, 3 vols., Vol. III: 1627 – 1634, (The Hague: Nijhoff, 1945), p. 302.

[32] Hartlib, "Ephemerides," *The Hartlib Papers* (cit. note 27), November 1635 - c. February 1636, 29/3/55B. "Nullus philosophorum scripsit ad huc Tractactus ex professo De Elemento Ignis præter Drebbelium per MS. illi ablatum vel retentum ab Hoft quodam qui brevi erit Consul Amstelrodamensis. . . ."

3. The Persona and Philosophical Perspectives of the Author

Duke Ernst's familiarity with Drebbel's other inventions, as well as the Moriaen provenance of the Gotha manuscript, set it in a context which makes its ascription to Drebbel the more probable. The *persona* and philosophical perspective of the author might also offer further reasons for attribution. In particular, the *Description* offers a fusion of alchemy and mechanics typical of Drebbel's other inventions, his persona, and his natural philosophy. The description of a series of motions within the oven ("should the coals go on too much and increase the heat, then the air in the glass dilates and pushes the mercury further, the mercury [pushes] the cork, and the cork [pushes] the handle of the spoon, and so the spoon again closes the airhole") encapsulates the way Drebbel reasoned about meteorological, macrocosmic processes by taking into account interrelated corpuscular and chemical causation (as in the consumption of air by the fire).

One can understand how this conception of his machine and the universe at large might easily be re-interpreted from a more mechanically inclined perspective. Indeed, in his *Description*, the author describes employing "mechanical manipulation" (*Mechanische* Handgrieffe) – that is, levers – for something which is not mechanical, i.e., the activity of fire and the motions of water and mercury. This grafting of mechanisms onto chemical and pneumatic processes mirrors Drebbel's other and prior physico-mechanical devices.[33] It was this fusion of alchemy and mechanics which led Robert Boyle to praise Drebbel's "much admir'd digesting furnace" and to suggest that "Chymistry may be very much advanc'd if the Practisers of it were well skill'd in Mechanicall contrivances" as was Drebbel.[34]

The author of the description, especially in the first-person Hamburg narrative, adopts a very aggressive artisanal stance vis-à-vis those who presume to be learned. He decried the "philosophers" and "sophists" who all had so much need of fire, but who had no means of managing it, and whose means of describing degrees of heat were so imprecise and variable. He was able, in one fell swoop or *fundament*, to offer an ingenious solution to both these problems, although he often stated that it would be easier to show than to describe his solutions. Furthermore, the author did not hesitate to

[33] Vera Keller, "Drebbel's Living Instruments, Hartmann's Microcosm and Libavius' Thelesmos: Epistemic Machines before Descartes," *History of Science*, March 2010, *48:1*: 39-74, p. 46.

[34] Robert Boyle, *Works of Boyle*, 14 vols., Vol. 13, edited by Michael Hunter (London: Pickering & Chatto, 2000), p. 298. Cited in Keller, "Drebbel's Living Instruments" (cit. note 33).

incorporate natural philosophical tags and speculations, such as the fear of the vacuum, into his eminently practical description. The author of the *Description* tightly interconnected machine design with more general physical, and here also geometrical, speculation.

Likewise, in his 1608 *On the Nature of the Elements*, Drebbel criticized those who wrote "fat books" as vain, and continually directed his readers to an illustrated demonstration of the interaction of air, water, and fire, as simpler to understand than a written description.[35] He had also informed King James I of his knowledge of the causes of all motion in the world, and his ability to demonstrate this knowledge through actual "living instruments" rather than mere words, despite the doubts of all the "clever wits."[36] The content, style, and persona of the *Description* correspond with those found in Drebbel's other writings, that is, of an aggressively artisanal philosopher, who confidently laid claim to a philosophical understanding of the universe through personal, hands-on experience of practical affairs.

4. Instrument Maker or Philosopher? Meteorological Theory and Practice

A self-regulating oven did serve a pre-eminently practical function. It was especially useful to alchemists who spent weeks, if not months toiling over complicated processes. Bruce White and Walter Woodward have recently related the interest of the colonial alchemist William White in Drebbel's fornacic design to the extremely practical pressure to save fuel in a colonial setting.[37] White described his oven in a catalog of secrets in Hartlib's papers as "lately made for the Kings vse that will in 24 hours bake bread for a 1000 men: and followe the Army foote for foote: by a frenchman prised at ten thousand li." Hartlib had also commented that Sir John Heydon, the hard-pressed Lieutenant General of the Royalist Ordinance office, "brought in a Calculation" as to how through Drebbel's oven "40. thousand lb. might bee

[35] Drebbel, *Ein kurtzer Tractat* (cit. note 2)," sollen wir grosse Bücher schreiben, Gott dar mit zu loben? Ist es nicht eittelheit?"

[36] Drebbel, *Wondervont* (cit. note 11), "Ten waer (o Coningh) dit so wel conde bewijsen met levendige instrumenten/ als met natuerlijcke reden/ soo en soude niet hebben bestaen dus veel te schrijven: Want my is wel bekent/ dat meest alle cloecke verstanden niet willen ghelooven/ dat wy dese verburghen oorsaken met onse vernunft moghen begrijpen."

[37] White and Woodward, "'A Most Exquisite Fellow'" (cit. note 27). See also William Newman, and Lawrence Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago: University of Chicago Press, 2002), pp. 158-161.

saved to the k[ing's] Army."[38] Contemporaries clearly considered the oven to be of great practical use in situations such as military campaigns and plantations. Hartlib himself recommended that the ovens "will bee good to bee communicated to New England."[39]

Having a thermostat on an oven seems so obviously sensible today that one wonders why it was not done before. However, affixing a thermostat to an oven was not the eminently practical innovation it appears to be today for a society which did not share our conception of temperature. The balance of humors in "temperament" changed to a measurement of movement, that is, "temperature." This shift entailed new views concerning the role of fire in the macrocosm. Drebbel's theories about heat as the motive force in the generation of winds and cyclical weather patterns long preceded his oven design, and offered the basis for it. Furthermore, the *Description* offers an account of the oven in which the idea of the thermometer emerged inseparably from the idea of feedback control. Both Drebbel's *Judicium* and *Regiment* were modeled on Drebbel's meteorological theories, in which heat played a central role in cyclical weather patterns.

Despite the current interest in artisanal knowledge, however, historians have been slow to treat Drebbel as a philosopher, even though he was so treated by many in the seventeenth century. Scholars have been more quick to point to the empirical and mechanical interests of figures already recognized as philosophers, such as Galileo, than to recover the philosophical interests of figures long sidelined as mechanicians and instrument makers.[40] The *Description* offers us the opportunity to shed light on one of Drebbel's most famous devices, and more importantly, to show how the material culture of the oven connected to the development of key natural concepts such as heat, cold, condensation, rarefaction and fire.

Recently, Craig Martin has sought to recuperate Aristotelian meteorology against the claim (leveled both in early modern times and more recently) that the field remained trapped in the search for syllogistically-proven

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[38] White and Woodward, "'A Most Exquisite Fellow'" (cit. note 27), p. 291. Hartlib, *Ephemerides, The Hartlib Papers* (cit. note 27), 29/5/73A, 1656.

[39] Hartlib, *Ephemerides, The Hartlib Papers* (cit. note 27), 29/3/52A. "Dr Hygenius hase an excellent remedy against the frost for hand and feet that they shal never bee frozen or hurt by it. Mr Haack hase promised to get it. It will bee good to bee communicated to New England with Kufflers Ovens."

[40] Recently, Drebbel, in contrast to Galileo, has been called a "Dutch machine maker," who "kept silent about the principle" on the basis of which his devices worked, who "never used his instrument to measure temperature," and whose biography of 1932 was "exhaustive." Matteo Valleriani, *Galileo Engineer* (Dordrecht: Springer, 2010), pp. 162-163.

truths, versus the contingent and probabilistic modes of experimental investigation. Martin has argued that the study of meteors, which dealt particularly with the world of changing matter, was peculiarly probabilistic, and therefore cannot be so distinguished from experimental natural philosophy. Meteorology owed its especially contingent status to its distance from more perfect and immutable natural bodies. The instability of meteors, such as the exhalations producing earthquakes, weather, and aerial phenomena, meant that they were unpredictable and could not form the basis for secure philosophy. There were other areas of Aristotelian natural philosophies which were less materialist and therefore philosophically more stable than meteorology, according to Martin.[41] By the mid-seventeenth century, Aristotelian meteorology underwent a wholesale, thoroughly materialist epistemological re-interpretation, at the hands of Niccolò Cabeo and others.

In a work from 1629, Cabeo himself stressed the philosophical significance of Drebbel's perpetual motion machine and its relationship to the devices used to measure degrees of cold in a room, which had recently become common throughout Italy.[42] One did not have to turn to Drebbel's devices alone, however. His work *A Short Treatise on the Nature of the Elements and how they cause Wind, Rain, Lightning, Thunder, and How they might be Used* (1608) already offered philosophical discussions of such phenomena.[43] He aspired to offer a causal account of weather patterns long before Cabeo did in 1646.[44] The greater certainty and the causal arguments Drebbel offered for meteors was why in 1626 the great encyclopedist at Herborn, Johann Heinrich Alsted, declared in a philosophical textbook that Drebbel's *On the Nature of the Elements* was the greatest work "on the generation of winds, rains, and other meteors."[45]

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[41] Craig Martin, *Renaissance Meteorology: Pomponazzi to Descartes* (Baltimore: Johns Hopkins University Press, 2011).

[42] Nicholas Cabeus, S.J. *Philosophia magnetica* (Cologne: Kinckius, 1629), p. 36.

[43] Drebbel, *Ein kurtzer Tractat* (cit. note 2).

[44] The treatment of phenomena of aerial rarefaction and condensation, thunder, lightning, heat, cold, seasonal change, and storms as continuing patterns rather than as single meteors was a perspective, Vladimir Jankoviç has argued, not generally assumed until the eighteenth century. Vladimir Jankoviç, *Reading the Skies: A Cultural History of English Weather, 1685-1820* (Manchester: Manchester University Press, 2000). Heinrich Wilhelm Dove, *The Law of Storms Considered in Connection with the Ordinary Movements of the Atmosphere* (London: Longman, Green, Longman, Roberts, and Green, 1862), p. 302.

[45] Johann Heinrich Alsted, *Compendium philosophicum* (Herborn: Georg Corvinus, 1626), p. 165: "Quisnam omnium optime descripserit generationem ventorum pluviarum, & similium meteororum? Cornelius Drebbel in tractatu de naturâ elementorum."

Alsted indicated his respect for Drebbel's text by reprinting the entire work in his philosophical compendium of 1626. Despite much acclaim in the seventeenth century, this text (translated in Drebbel's lifetime into German, French, and Latin) has not been considered seriously in modern studies. Furthermore, newly discovered texts such as the *Description* (reproduced and translated here) allow for unprecedented access to the explanations offered for Drebbel's devices and thus their connections to his philosophical works. The highly sensitive devices Drebbel engineered relied upon his studies of heat, cold, and cyclical weather patterns for their startling effects. The self-regulating oven, now anachronistically considered the first feedback control mechanism, owed its ingenuity to Drebbel's insights about causation in weather. The *Description* illustrates how the cyclical patterns of Drebbel's "feedback control" were conceptualized inseparably from the thermometer, and how both appeared in the context of philosophical speculations about heat, air, fire, and the production of winds.

Drebbel's *On the Nature of the Elements* already connected a wide-ranging, if concise, study of meteors in the macrocosm to usage (particularly within the microcosm of the alchemical alembic). Alsted and others admired how Drebbel connected causal natural philosophy to use, and how he deployed material demonstrations to showcase his ideas, such as his view of the generation of winds. This theory countered the idea attributed at the time to Aristotle of a decuple rate of expansion. The latter kept the elements within a certain proportion. As Jan Amos Comenius wrote, "Aristotle thought that the Elements were in a tenfold proportion to one another; but later men have found them near an hundred-fold. . . . That is, that of one drop of earth is made by rarifaction ten drops of water; and of one of water ten of air . . . . But this very proportion varies, because the air is in it selfe sometimes thicker and grosser, sometimes more rare and thin."[46] Drebbel's denial of a proportional relationship between the elements countered the concept of a temperament composed of different proportions of the elements. The relationship of one element to another could not be assumed based on their set rate of rarefaction. It was variable, and it could vary across a vast scale. Wind was produced by the extreme rarefaction of air through heat, as Drebbel illustrated in his text with a woodcut of a heated retort, referred to in the text. A retort suspended with its mouth in a vessel of water demonstrated Drebbel's theory of the origin of winds.

[46] Jan Amos Comenius, *Naturall philosophie reformed by divine light, or, A synopsis of physicks* (London: Thomas Pierrepont, 1651), pp. 82-84.

Upon heating the retort, air rushed out into the vessel of water. Upon cooling, the emptied retort drew water up within itself above the level of the vessel of water, and the more it had been previously heated, the more water it would draw up.

This demonstration has been called a primitive "thermoscope" and used as evidence for the simplicity of Drebbel's instruments and thus his failure to invent the thermometer. The intent of this demonstration, however, was not metric. Contemporaries noted the novelty of the demonstration and the theory of winds it demonstrated.[47] One Georg Scholtz, for example, defended Aristotle's theory of wind formation against Drebbel's, claiming that Drebbel could not use his "invention" in order to learn anything about macrocosmic processes.[48]

Rather than being just a thought experiment, the demonstration was also reproduced by Drebbel's readers. Isaac Beeckman, for instance, noted reproducing the demonstration in 1619.[49] Beeckman considered fire as

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[47] This was so despite the fact that the phenomenon was becoming common knowledge among practicing engineers and alchemists (well before the modern editions of Hero's *Pneumatica*). See Graham Hollister Short, "The Formation of Knowledge Concerning Atmospheric Pressure and Steam Power in Europe from Aleotti (1589) to Papin (1690)," *History of Technology*, 2004, *25*:137. A related demonstration was also described in the vacuum debates. See Charles B. Schmitt, "Experimental evidence for and against a void: the sixteenth-century arguments," *Isis*, 1967, *58:3*: 352-366, pp. 361-362.

[48] Georg Scholtz, *Sphaera Mirabilium Creationis, Creaturae, Creatoris* (Hamburg: Bismarck, 1654), pp. 213-421. "Drebbelius in tractatu de elementis nititur demonstrare opus ventorum per inventum quoddam, ubî in vas retortum super aquam suspensum mediante igne pellit vapores, quos in vase clauso gyrantes, dicit esse similitudinem ventorum, qui ita generentur & moveantur. Sed quomodo haec ad mundum majorem spectant, ubi venti in aere libero circumvagantur, non autem claustris vasorum cohibit in furorem agitantur? Vbi saepè nullis apparentibus vaporibus vel nubibus, maximi ventorum flatus percipiuntur." Libavius voiced similar reservations about the ability to find proof in the retort demonstration, pointing to the much greater complexity of geography compared to the shape of the retort. See Andreas Libavius, "Apocalypseos Hermeticae Pars Posterior, quae est Divinationum Hermeticarum Heptas (henceforth Hermetic Revelations)," in *Syntagma Arcanorum Chymicorum*, 2 vols., Vol. 2 (Frankfurt a. M.: Peter Kopff, 1613), p. 372. "Pergit in sua physica ventosa, & argumento commotionum in vitro Hermetico de varietate halituum seu flatuum maioris mundi disserit. Sane si vellemus omnem ventorum motum ubivis terrarum & in mari excutere, fortasse Vulcanus, & Aeolus noster Hermeticus non sufficeret, cum in sua sphaera non habeat sinus varios, & montes, planicies, cavernas, & alia quae flatus mirifice mutare possunt, uti testantur navigationes Indicae, & Americanae, in quibus admiranda de ventis legimus, rationibus non tanta facilitate se prodentibus."

[49] Isaac Beeckman, *Journal tenu par Isaac Beeckman de 1604 à 1634*, 3 vols., Vol. I: 1604-1619 (Hague: M. Nijhoff, 1939), p. 346. "Den 10 November te Middelb., occasionem praebente *cap. 6* libri Drebbelij Alcmariensis, gedruckt te Haerlem, *Van den natuyre der Elementen*, int Duytsch."

the name of the motion of a combination of *minima*.[50] He described how through this motion one could determine "the particular temperament of every room, and how much one differs from the other in hot and cold (die het temperament van elcke camer int bysonder weten conde; hoeveel deen van dander in hitte ende coude verschilde)." He continued to describe various instruments and perpetual motions operating by means of this movement, including Drebbel's.[51]

In short, new ideas about motion unrestricted by proportionate expansion or temperament preceded the idea of temperature. Just because these ideas concerned motion, however, does not mean that they therefore supported a mechanistic philosophy. Drebbel's ideas about motion were developed primarily in an alchemical context, to which he applied mechanics.[52] Temperature emerged as the marks applied by man to measure this motion. So-called feedback control emerged as an application of levers to this motion. Both depended upon Drebbel's demonstration of how the elements transformed into one another in a cyclical motion. This was why for the author of the *Description*, there was but one foundation to both the thermometer and to feedback control – the motion of air.

Drebbel placed the oven in the context of weather at large. He pointed out that changes in weather affected the interior warmth of the oven, even if the amount of fuel remained the same. By attaching a weather glass to the oven, Drebbel transformed the variable yet cyclical change in temperature from a defect in oven design into an asset, as the main idea ("*fundament*") underlying the self-correcting motion of his oven.

5. The "Thermometer" within the *Description*

The *Description* is equally divided in both versions between an account of the *Judicium* or *Vas judicatorium* (what we would call the thermometer)

[50] Isaac Beeckman, *Journal*, (cit. note 31), p. 198: 27th May, 1622. "Dicendum igitur ignis materiam esse sulfur, oleum, saevum et reliqua inflammabilia. Sed ea non sunt ignis cùm quiescunt, sed tum demum vocantur *ignis*, cùm in minimas partes divisa sunt eaeque partes celerrimè moventur; prioresque semper sequentes, subsequuntur, per quem motum continuum disijcitur aer et acquiritur locus capacior, sine quo motu iste peragi non possit…"

[51] Beeckman, *Journal*, (cit. note 31), pp. 198-205.

[52] On chemical motion more generally, see Allen Debus, "Motion in the Chemical Texts of the Renaissance," *Isis*, 1974, *64:1*:4-17. Similarly, on the interpretation of Watt's theories about steam power being primarily chemical, David Philip Miller, "Seeing the Chemical Steam through the Historical Fog: Watt's Steam Engine as Chemistry," *Annals of Science*, 2008, *65*:47–72.

and the "*Regiment*" (what we would call the feed-back control mechanism). The regiment of fire (*regimen ignis*) was a common alchemical term for the management of the fire. It could include any manner, process or design specifying the duration and varying heat of a fire within a furnace, typically according to four degrees. The academic alchemist Andreas Libavius went so far as to identify the regiment of fire as the "science (*scientia*)" of *pyronomia*. This science, he argued, was best learned in practice through the eye and the hand, since the four degrees were measured by how they felt to the artisan.[53] The "*judicium*" of fire, by contrast, was not a familiar alchemical term. This was the novel instrument that took the task of measuring the fire away from the hand of the artisan and embodied it within a device.

In the oven design described here, the *regimen* and the *judicium* were two separate instruments, although in later ovens they were merged into one (a marginal side-note points out that Reger had an oven with a single glass, as did the version described by Augustus Küffler). One instrument indicated the *gradus* or degree of heat far more precisely than the very general measurements used in alchemical texts, such as the melting of wax, as the author points out. He specifies that the measurements on the *judicium* can be divided into as many degrees as one wishes, although the version he describes has seven levels. The second glass, the *Regiment*, situated next to the *Judicium*, deployed the motion of the mercury to lift and close a lever covering the air supply for the oven. The mercury "captures and encloses the air inside, so that it can no longer condense or rarify, or the mercury follows it very closely, and betakes itself above or below the equilibrium, according to how the air dilates or condenses through the heat." "When the heat in the oven increases" the mercury pushes against a cork resting upon it, "but when it decreases, the cork goes back in again." The cork in turn pressed upon a lever that opened and closed an air hole. As the heat increased and the mercury rose, the cork's motion would cause the lever to depress, closing the air hole, limiting the air supply, and thus reducing the fire's heat. As the heat decreased, the opposite motion would increase the air supply.

The author of this account considered his oven to include two new inventions, the *Judicium* and *Regiment*, which we would call today the thermometer and feedback control mechanism. The term "thermometer" was unknown to the author (although the "weather glass," which displayed changes in both what we would call air pressure and temperature, was

[53] Andreas Libavius, "de Pyronomia," *Alchemia* (Frankfurt a.M.: Kopff, 1597), pp. 24-5. "Pyronomia est caloris ad suas operas adhibendi, ignisque regendi scientia."

known to him). He did not conceptualize his *Judicium* as a stand-alone instrument which might function independently of the *Regiment* and in other contexts. The equal attention given to both the *Judicium* and *Regiment* points to the importance and novelty of both ideas and to their development in tandem. The *judicium* emerged from the attention paid to the regiment of fire in the alchemical tradition. Equally as new as the *judicium*, however, was the new role for the regiment of fire as a distinct object rather than an entire range of practices for managing heat.

These two instruments cannot be understood or judged individually. For example, a central flaw of Drebbel's scale was that his degrees were not keyed to any natural scale which might aid in the production of a universal metric language. Sanctorius used a burning candle and snow as his two extremes, while Carlo Renaldi was the first to key the thermometer to the boiling and freezing of water in 1694.[54] Drebbel suggested dividing the scale "into equal degrees, as many as is desired." His suggestion of seven degrees appears to be a random number not associated with any natural scale. Not keying the scale to nature might seem like a flaw. However, at a time when temperature was beginning to separate from the concept of temperament, an arbitrary scale shifting the measurement of heat away from the traditional four grades disassociated the idea of degrees from that of natural temperament based on the four elements.

Robert Fludd also employed a scale of seven degrees, which does not correspond to previous temperamental scales of four degrees, or alternatively of eight (four of calidity and four of frigidity).[55] Fludd, however, tied this scale again into a system of temperamental correspondence. The center entailed perfect balance and health, whereas seven degrees led upward to "melacholicus humor" (melancholic humor) and seven degrees led downward to "bilis atra" (black bile).[56] According to this idea of balance, exactitude could be found at the center. This viewpoint suggests why some might be hesitant to key the degrees to the two extremes used by others seeking better calibration and exactitude.

The thermometer, as it evolved out of an idea of four degrees and humoral balance, was centered for some around an idea of equilibrium rather than of extremes. Drebbel designed his thermometer around the normal ambient

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[54] Barnett, "The Development of Thermometry," (cit. note 3), p. 296.

[55] Barnett, "The Development of Thermometry," (cit. note 3), pp. 272-3, cf. 279.

[56] Robert Fludd, *Integrum morborum mysterium: sive medicinae catholicae* (Frankfurt a.M.: Fitzer, 1631), Vol. 2, p. 325. Allen G. Debus, "Key to Two Worlds: Robert Fludd's Weather Glass," *Chemistry, Alchemy, and the New Philosophy, 1550-1700: Studies in the History of Science and Medicine* (London: Variorum Reprints, 1987).

air of an unheated oven, as the mercury moved "above or below the aequilibrium," which made his scale less useful for calibrating temperature than thermometers keyed to two extremes. While a notion of equilibrium might not be helpful to the design of a temperature scale, it was, however, this very focus on equilibrium and its maintenance which was the foundation of Drebbel's regiment of fire.

Does the *Description*, then, prove that Drebbel invented the thermometer? Even were the ascription to be universally accepted and an early date for it found, the answer to that question would depend upon the meaning of the term "thermometer." Defining it in the eighteenth-century sense would anachronistically cut away the entangled nature of the object. At its very first coining, "thermometer" included both the "*judicium*" and the "*regiment*." In 1624, the same year that the Küfflers described the oven to Peiresc in Paris, the term thermometer was coined by Leurechon/Etten. Among the many uses that author had offered for the thermometer in the 1620's was keeping "a room, a furnace, a stove, in a constant heat by making it so that the water in the thermometer always stays on the same degree."[57] In other words, the thermometer served not only a diagnostic, but a regulatory function even in this first use of the term. When Caspar Ens decided to add "Drebbelian Instrument," to Leurechon's "thermomètre" in 1636, he may well have been referring not only to the diagnosis of heat and cold, but to Drebbel's application of it to control the constant heat of a furnace as a new regiment of fire.

Conclusion

Universal measurements allow science to be deployed across cultures, and therefore appear to offer a view from nowhere. In order to contribute to, for instance, Réaumur's universal science of climate, thermometers needed to be "disentangled from their context of production or from that of personal and singular use, and in principle become commodities that could travel everywhere and be read by anybody."[58] The development of universal metric languages such as temperature and instruments such as thermometers

[57] Leurechon or van Etten, *La récréation mathématiques* (cit. note 4), p. 77. "On peut entretenir une chambre, un fourneau, une estuue, en chaleur tousiours égale faisant en sorte que l'eau du thermomètre demeure tousiours sur un mesme degré."

[58] Marie-Noëlle Bourguet, Christian Licoppe, and H. Otto Sibum (eds.), *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century* (London and New York: Routledge, 2002), p. 10.

allowed for the disembodiment of natural knowledge and the separation of universal science from severely localized ways of assessing and engaging with nature. With the assessment of nature entrusted to instruments, natural knowledge rested, it appeared, not within the body of the ingenious artisan, but upon the ability to command a panoply of objective scientific instruments.[59] Thus, the history of instrumentation comes to entail the history of scientific personae and authority.

The rapid development of a distinct industry of scientific instrument-making restructured the relationships between instrument makers and philosophers over the course of the seventeenth century. To take the example of a single family, the development of a distinct trade in scientific instruments occasioned the professional separation of instrument makers such as Samuel van Musschenbroek (1640-1681) of Leiden both from his craftsman father, Joost van Musschenbroek (1614-1693), who was a lamp-maker, and from his son, Pieter van Musschenbroek (1692-1761), an academic who discussed the design of thermometers within philosophical works.[60]

Eighteenth-century chemists developed relationships with instrument makers and drew upon those relationships in theorizing about the nature of

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[59] Andrew Barry, "The History of Measurement and the Engineers of Space," *The British Journal for the History of Science*, 1993, *26*:459-468; Stevin Shapin, "Here and Everywhere: Sociology of Scientific Knowledge," *Annual Review of Sociology*, 1995, *21*:289-321 and "Placing the View from Nowhere: Historical and Sociological Problems in the Location of Science," *Transactions of the Institute of British Geographers*, 1998, *23*:5-12, p. 7; and Marie-Noëlle Bourguet, Christian Licoppe, and H. Otto Sibum (eds.), *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century* (London and New York: Routledge, 2002). Peter Galison and Lorraine Daston, "Scientific Coordination as Ethos and Epistemology," in *Instruments in Art and Science: On the Architectonics of Cultural Boundaries in the 17th Century*, edited by Helmar Schramm, Ludger Schwarte and Jan Lazardzig (Berlin: de Gruyter, 2008), pp. 296-333.

[60] James A. Bennett, "Shopping for Instruments in Paris and London", in *Merchants & Marvels: Commerce, Science and Art in Early Modern Europe*, edited by Pamela Smith and Paula Findlen (New York, NY: Routledge, 2002), pp. 370-398; Gerhard Wiesenfeldt, "The Order of Knowledge, of Instruments, and of Leiden University, ca 1700," in *Instruments in Art and Science: On the Architectonics of Cultural Boundaries in the 17th Century*, edited by Helmar Schramm, Ludger Schwarte, and Jan Lazardzig (Berlin: Walter de Gruyter, 2008), pp. 222-234; Anne C. van Helden, "Theory and Practice in Air-Pump Construction: The Cooperation Between Willem Jacob's Gravesande and Jan van Musschenbroeck," *Annals of Science*, 1994, *51*: 477-495; C. de Pater, "Petrus van Musschenbroek, 1692-1761," in *Van Stevin tot Lorentz. Portretten van achttien Nederlandse natuurwetenschappers*, edited by A. J. Kox (Bert Bakker: Amsterdam, 1990), pp. 93-4; Jan van Musschenbroek, *Liste de diverses machines, de physique, de mathématique, d'anatomie et de chirurgie, qui se trouvent chez Jean Van Musschenbroek à Leyden* (Leiden: N.A., [1739]); and Pieter van Musschenbroek, *Elementa physicae conscripta in usus academicos* (Leiden: Luchtmans, 1741), pp. 316-321.

fire and its role in thermometer design.[61] Such relationships offer an example of knowledge traveling from the world of the artisan to the philosopher or vice versa. Before such distinct identities existed, however, theorizing about physical causes could take place simultaneously with the development of instrumentation and its application in useful devices, such as ovens. The very disentanglement of the measurement of degrees of heat from the body of the artisan took place for entangled reasons. Alchemy, meteorology, natural magic, courtly display and military engineering not only shaped the self-regulating oven, but the oven continued to be used in a variety of ways. As the *Description* states, the movement of the oven, besides being eminently practical, offered those "who see it a very pleasant speculation." As was the case for other works of the period bridging the traditions of natural magic and experiment, the oven combined a discussion of philosophical causes with practical utility and delightful entertainment.[62]

A historiographic refashioning of Drebbel into an inventor has effectively effaced such entanglements by allowing his inventions to be removed from their philosophical contexts in order to do service to a thesis of a mechanizing world view.[63] The historians who established the identity for the oven as the first "feedback control" mechanism, considered the oven as exemplifying a new mechanical worldview inspiring mechanistic philosophies.[64] Such a context for the oven ignores Drebbel's own alchemical and vitalist natural philosophy, which once enjoyed wide recognition. The oven was preceded by other philosophical devices built to display Drebbel's theories concerning the role of contraction and expansion in the transmutation of the elements.[65]

Historians and sociologists of science have been interested in re-entangling precision instruments in order to trace the process through

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[61] Jan Golinski, "'Fit Instruments': Thermometers in Eighteenth-Century Chemistry", in *Instruments and Experimentation in the History of Chemistry*, edited by Frederic L. Holmes, Trevor H. Levere (Cambridge, MA: MIT, 2000), pp. 185-210.

[62] A parallel would be Salomon de Caus, *Les raisons des forces mouvantes avec diverses machines tant utiles que plaisantes auxquelles sont adjoints plusieurs desseings de grotes et fontaines* (Frankfurt a. M.: Jan Norton, 1615).

[63] Derek J. de Solla Price, "Automata and the Origins of Mechanism and Mechanistic Philosophy," *Technology and Culture*, 1964, *5:1*:9-23.

[64] Otto Mayr, *The Origins of Feedback Control* (Cambridge: MIT Press, 1970) and Silvio Bedini, "Role of the Automata in the History of Technology," in *Patrons, Artisans and Instruments of Science, 1600-1750* (Brookfield: Ashgate, 1999). Bernhard Dotzler has set Drebbel's feed-back control within the context of reckoning machines and calculators (and a dead end in the context of that development). Dotzler, *Papiermaschinen* (cit. note 8), pp. 219-221.

[65] On these machines, see Keller, "Drebbel's Living Instruments" (cit. note 33).

which science came to appear universal. The *Description* re-entangles the thermometer with the self-regulating oven, the world of alchemical practice, and new meteorological theories and philosophical concepts connected to those objects and practices. The later development of a distinct role for the scientific instrument maker should not obscure such earlier relationships between philosophical and practical authority. Drebbel's self-regulating oven can be situated at a moment and in a context where such diverse forms of expertise remained inextricable. As Rienk Vermij reminds us, instrument making should not be presumed to be subject to philosophy: "Sometimes instruments really 'made' the philosophers."[66]

[66] Rienk Vermij, "Instruments and the Making of a Philosopher. Spinoza's Career in Optics," *Intellectual History Review*, 2013, *23*:65-81, p. 81.

Text and Translation of the Manuscript "Drebbel's Description of his Circulating Oven communicated by D. Reger (Drebbelii Beschreibung Seiners Circulir Ofens communic[ata] a D. Reger)

Editorial Principles

I have modernized punctuation in the translation, yet retained italicization. I have also replaced alchemical symbols with their Latin terms within brackets. I have represented the sharp "s" with a double "s." Segments of the Hamburg manuscript which do not appear in the Gotha manuscript are highlighted in bold.

Hamburg Cod. alch. 652, S. 430-435
[430] *Drebbelii* Beschreibung Seiners *Circulir* Ofens *com*[*m*]*unic*[*ata*] *a D. Reger*.

Wir wollen alhie beschreiben, wie durch *Mechanische* Handgrieffe das [*ignis*], so aller Weisen mit den *Sophisten* gemein haben, gantz *accurat* kan *regieret* worden. Mercke; In allen Gemeinen Ofen, wie künstl. dieselben durch Menschen seyn erdacht, es sey, dass Sie mit Kohlen od. Lampen [*ignis*] erhitzet werden, befinden sich in dem Gebrauch diese 2. Mängel:

A. Dass Sie den *grad* ihrer Hitze nicht eigentl. zu wissen thun anders, als man etwan mit Händen tasten, od. sonsten auss anderen proben mehr etl. massen abnehmen kan, aber doch so eigentl. u. gewiss nicht mag wissen. **Bisweilen heissen die *Philosophi* einen solchen *grad* der Hitze geben, dass das Wachss darinnen schmeltze, u. also ohne fernere Zuhitzung geschmoltzen bleibe, u. ist nicht ohne, wann man solches ihrem Begehren nach ins Werck stellen könte, dass man auch etl. massen damit Zu lande, und dem *grad* der Hitze ohngefehr muthmassen könte. Wann nun gleich der Ofen so viel an ihme ist, bequehm gemacht würden, in ihn einen solchen grad der gesuchten Hitze zu stellen, so lasset doch die aussere herumb schwebende Lufft und unordentl. Gewitter ihm nicht zu, dass er in einem u. demselben *grad* erhalten, u. denselben beständig erzeigen könte. Dann ein und desselbe [*ignis*] wircket im Som[m]er einen stärckeren *grad* alss im Winter und wie die ausserl. Lufft, also verändert auch die innerl. Wärme unangesehen der Ofen auf eine Weise regieret wird, und** diss ist nun der Zweyte Mangel an allen Ofen, dass Sie wegen unbeständigem Gewitter keiner beständigen grad halten können. Diesem Gebrechen vor zu kom[m]en seynd Zwo Mittel erfunden worden, auss einem *fundament* dadurch man des veränderl. Gewitters ungeachtet nicht allein einen jeder Ofen in dem begehrten grad der Hitze bringen und darinn erhalten, sondren auch jeder Zeit gantz gnau wissen kan, wie Heiss er ist, und ob er sich verandere oder nicht. Solch *fundament* ist anders nicht, alss eben die Lufft selbst; Wann nun dieselbe durch ein beweglich *Corpus*.

[431] in ein Glass also beschlossen wird, dass bey aus Aussdähnung od. Einziehung der Lufft sich das Corpus mit beweget, u. dann Zwo solcher Gläser doch unterschiedl. Arth u. Form einem Ofen *appliciret*, so hat man beydes ein unfehlbahres *Judicium* und auch *Regimen Ignis*. Dann, weil die gefangene Lufft im Glase wann es dem Ofen einverleibet, mit der beschlossen Lufft im Ofen nothwendig aller dings übereinstimmet, *quoad gradum caloris*, so folget, wann ich der Lufft im Glase ihren *gradum* eigentl. und *perfect* erfahren kan, dass mihr dann auch des Ofens Hitze Zugleich bekand wird. Man hat Wetter Gläser daran man sehen kan, ob und wie viel ein Tag kälter od. wärmer sey, alss der andern oder eine Kammer alss die andere dann ein blauw Wasser in einer gläsern *fiole* in Kälte *coarctat intus aërem propter fugam vacui*, und zeucht sich nach der Kugel hin wiederumb, **wann durch die Wärme die inwendig beschlossene Lufft sich *dilatiret*, und ein grösser *Spatium* suchet, so muss ihm das Wasser weichen, u. sich herabgegeben**. Wer nun ein solches Glass od. *Instrument* gesehen hat, und dasselben im Grund verstehet, u. *appliciren* kan, der hat *Caloris judicium et Regimen*.

Nehmlich *quoad Judicium* also:

Man muss eine *fiol* eines sehr engen Halses heben nicht so weit alss ein gemein Feder Kiel od. so eng, alss man Sie haben kan, so mag die Kugel auch desto kleiner seyn im Diametro, wie eine Halbe Nuss ohngefehr, die bieget man bey der Kugel etwass krumb, wie hernach zu sehen, damit Sie mit der Kugel in den Oefen eingemauert werden, und mit dem Halse an der Wand des Ofens herauss hangen könne. Wann mans so weit hat, so erhitzet man den Ofen stärcker, als man in seiner vorhabenden Arbeit ja gedencket Zu thun, so *dilatiret* sich die Lufft im Glase, u. gehet frey durch den Halss hindurch wass übrig ist und bey solcher Hitze im Glase nicht herbergen kan, in wehren der solcher Hitze bequehme man in einem Tiegel od. anderen Geschirr.

[432] den Mund der *fiolen*, dass er etwass tieff in [*mercu*]*rio* hinein reiche, und mache es also aneinander feste, und lasse den Ofen erkalten; So bald nun die Hitze des Ofens ein wenig abnimmt, so will die Lufft in der *fiol* sich *condensiren*, und muss der [*mercuri*]*us* derselben folgen *ne detur vacuum*. Nun hat man zur Seiten des Halses der *fiolen* ein Messing Blech in gleiche

gradus getheilet so viel man will, daran man sehen kan, wie hoch der [*mercur*]*ius* steiget. Wann der Ofen gantz kalt ist, das ist *null grad*, dann so folgen herabwerths des Wassers 1.2.3.4.5.6.7. in der Abtheilung; Wann nun der Ofen wieder erhitzet wird, so steiget der [*mercur*]*ius*, durch diese *gradus* wieder herab, u. kann man jeder Zeit wissen wie Heiss der Ofen ist.

2. *Quoad Regimen*

Wie man aber den Ofen also *regiren* möge, dass der [*mercur*]*ius* nicht auf und nieder steigen, sondern auf der begehrten *grad* stehen bleibe, komt auss eben denselben *fundament*, und ist an ihme selbst verständlich, gleichwohl aber leichter zu zeigen, alss zu beschreiben umb der verschiedenen *Instrumenten* willen, die dazu von nöthen seyn. Das *Fundament* aber bestehet in ein ander Glass, wie *in Margine* aber zeichnet daselbe wird zugleich neben den anderen an einem und denselben Orth in den Ofen eingemauert, so dass beede Köpffe in dem Ofen kommen, und die Hälse herauss. Nun komt auch [*mercuri*]*us* in diss Glass, welcher die Lufft darinnen fänget u. beschleusst, also, dass dieselbe sich weder zusammen ziehen noch aussdehnen kan, oder der [*mercuri*]*us* folget ihme auf dem Fusse nach, begiebet sich auss dem *aequilibrio* hinter sich oder für sich nachdehm sich die Lufft durch die Hitze *dilatiret* od. *condensiret*. Durch dieses Glass und des [*mercur*]*ii* verschiedene Bewegung wird das *Regimen* nach den Willen des Künstlers beständig erhalten, und gehet also zu.

[433] 1. Ruhet auf dem [*mercur*]*io* ein gedrehetes Höltzlein, u. gehet über dem Halse des *Regier* Glasers herauss, u. dieses Hölzl folget dem [*mercur*]*io* also; Nimmt die Hitze im Ofen zu, so steiget das Höltzlein etwass in die Höhe auss dem Halse herauss, nimmt Sie aber ab, so kriegt [keucht] es etwas wieder hinein.

2. Man muss einen Leffel haben mit einem besondern Stiel, welcher in der Mitten ohngefehr ein Zwerg Eysen in *form* eines Creutzes haben; Mit diesen Axibus lieget der Leffel auf Zwo erhabenen Blechen, also dass, wann das eine Theil des Leffel abwerts gehet, das andere wieder unter gehet.

3. Muss der Stiehl an dem Höltzgen fest seyn, dass auf dem [*mercur*]*io* ruhet vermittelst einer Schrauben, die im Stiehl des Leffels seine Mutter hat, und im Höltzgen fest ist, undt der Leffel bedecket das Lufftloch, das den Ofen *regiren* soll, dieses Loch und der Leffel beyde von Messing oder [*aes*] werden so geheb auf ein ander geschliffen, dass wann der Leffel auf das Loch rühret, die Kohlen keine Lufft haben, und also nothwendig aussgehen müssen, u. hierinnen bestehet das gantze *Regiment*. Dann wann man

der Ofen in den begehrten *grad* hat, welches das *Judicium* zu erkennen giebet, so machet man gantz behendt welches aber besser zu weisen, als zu beschreiben, dass das Höltzgen ausser dem [*mercur*]*io in aequilibrio constituto* auflieget und der Leffel zugleich auch das Loch geheb beschliesse. So bald die Kohlen beginnen auss zu gehen, und der Ofen nun etwass Kalter wird, so *condensiret* sich die Lufft in *Vase directorio* so wohl auch in den anderen, dann sie liegen in einem Orth neben ein ander. Wann sich aber die Lufft *condensiret*, so laufft auch der [*mercuri*]*us* zurück, u. mit ihme das Höltzlein, so auf ihn ruhet, wie auch der Stiehl des Leffelss, und wann der Stiehl unterwerts gehet, so gehet auch der Leffel vom Lufftloch, u[nd] giebet dem Kohlen wieder Lufft zu brennen, wollen die Kohlen zu sehr angehen, und die Hitze vermehren so *dilatirt* sich die Lufft im Glase, und treibet den [*mercuri*]*um* fort, der [*mercuri*]*us*.

[434] das Höltzl. und derselbe den Stiehl des Leffels, und also machet der Leffel das Lufftloch wieder zu, also kan der Ofen weder kälter noch wärmer werden, dann will er kalt werden, so thut sich der Leffel auf, will er zu warm werden, so schliesset er sich wieder zu, u[nd] giebet dehm, der es siehet, eine gantz angenehme *Speculation*. In dem Glase AB von Zwo Stücken AC das andere BE zu sammen gebunden ist sonderlich zu *observiren* dass die *Linea* CD muss in die Köhlen hineingehen, biss auf das *punctlein* D. Dann wann die geringste Lufft gegen eine Fuge aussdringen kan, so ist es unmüglich, dass man sich halten könne, drumb muss nicht Fuge gegen Fuge, sondern Fuge gegen Glass kommen. Die Gläser nun in einander zubinden muss man nehmen erstl. Werck von Flachss, dieselbe bestreifen mit *Sigillo Hermetis*, u[nd] damit die Gläser an ein ander binden, darnach mit einem Tuch od. Leinen Band gleichfalss eingetunckt umbweider. Wann das Tuch nun trocken ist Rx. gemeinen Topfer Leim mit Schäffer Wolle wohl durch gearbeitet ohne einigen anderen Zusatz den Enge über das Band, will das nicht halten, so bestreiche den trocknen Leim mit gesottenen Leim, wie die Schüsseler od. Zinnen Giesser gebrauchen, so ist das meine noch endl. bestrichen, ehe es halten wollen. Dann wir haben ihme die Zeit nicht gegeben, dass es recht trocknen könte. Die Kugel von der *fiol* muss nirgends anrühren alss auf der Stein, darauf Sie ruhet, dero halben wir es ohngefehr beym halse mit Leimen zugemacht.

J.K. Ist das *Vas judicatorium*, der Halss muss also gebogen werden, dass keine *Materie* in der Kugel liegen bleibe, der Halss muss gantz enge seyn, man macht den Ofen überhitzig, alss man ihn gedencket zu gebrauchen 2. Tage lang, dermit das Glass HK der Lufft entlediget werden, wann es in solcher Hitze 2. Tage gestanden, so geusst man [*mercuri*]*um* in das Geschirr u. lässt den Ofen erkelten, so steiget der [*mercuri*]*us* in die Höhe.

(D. Reger hat es nun von einem Glase. Ins eine Loch vom Ofen komt dieses, ins andere, dass nechst daran, das erste.
[435] (An der Leffel hat D. Reger ein *Perpendicul* von Messing, das kan ab und niedergelassen werden, u[nd] wird feste geschraubet)
B. der Leffel
den Halss oben auf den Ofen
***Sustentaculum* aufn Ofen, wo die *axes* drauf liegen.**

Drebbel's Description of His Circulating Oven Communicated by D. Reger

We shall describe here how fire, which all the Sages and the Sophists have in common, can be governed very accurately through mechanical manipulation. Consider: all the common ovens have in practice these two defects, however artfully they have been constructed by men, and whether they heat the fire with coals or with lamps:

A. That they do nothing to know the degree of their heat. They feel it by hand or sometimes they can test it with some other measure, but they are unable to know it exactly. At times the Philosophers prescribe that one should give such a degree of heat that wax melts in it, and without further heating stays molten. One can only follow their instructions in practice if one has some basic measure to estimate from the outside the approximate degree of heat. However, when one does his best to make the oven perfectly suitable and to set it at a degree of desired heat, then the air and the disorderly weather swirling around outside does not permit him to maintain it in the same degree, and to show it to be continually the same. Because one and the same fire produces a stronger degree in the summer than in the winter, and as the outside air changes, so too does the interior heat, even though the oven has been governed in the same way, and this is now the second defect of all ovens, that they, due to inconstant weather, cannot keep a steady degree. In order to make up for these defects, two means have been invented, out of the same *fundament* through which one can, despite the changeable weather, not only bring and hold every oven to the desired degree, but also at any time, one can know precisely how hot it is, and whether it has changed or not. This *fundament* is nothing other than the air itself; when this is closed up in a glass with a moveable body, so that the body moves along with the rarefying or condensing of the air, and then two of these glasses, although of different forms, are applied to one oven, then one has both an infallible measurement and control of the fire. For if the captured air in the glass has been attached to the oven, in such a way that it corresponds with the enclosed air in the oven according to the degree of heat, then it follows that if I can know the degree of the air in the glass perfectly, then the heat of the oven will also be known to me. People have weather glasses in which one can see whether and by how much one day is colder or warmer than another, or one room than another, since a blue water in a glass vial in the cold condenses into the air in order to avoid a vacuum, and drags itself again toward the bulb, when through the heat, the interior enclosed air dilates, and seeks a greater space, and so the water must give way to it. Whoever has seen such a glass or instrument and fundamentally understood it and can apply it, he has a measurement and a control of heat.

The measurement is this:

One must have a vial with a very narrow neck- not so wide as an ordinary quill, or so narrow as one can possibly have it, but so that the bulb is smaller in diameter than about a half nut. Then one bends it a little crooked by the bulb, as can be seen below, so that it can be walled into the oven with the neck along the wall of the oven hanging out. When one has gotten this far, then heat the oven stronger than one in the intended task would ever plan on doing, and then the air dilates itself in the glass, and what is left over goes free through the neck and with such a heat cannot stay in the glass, and keeping the heat suitable, fasten to each other in a pan or other pot the mouth of the vial, so that it reaches somewhat deeply into the mercury, and let the oven cool; as soon as the heat in the oven goes down a little, the air in the vial will condense, and the mercury must follow it lest there be a vacuum.

Divide a brass plate on the side of the neck of the vial into equal degrees, as many as is desired, so that one can see how the mercury rises. When the oven is completely cold, that is zero degrees, and so it goes upwards with the water divided into 1.2.3.4.5.6.7 When then the oven is heated again, then the mercury will go back up through these degrees, and one can know at any time how hot the oven is.

2. *The Control*

How one can also govern the oven, so that the mercury does not rise up and down, but stays at the desired degree, comes from the same *fundament*, and is understandable through it, although it will be easier to show than to describe the different instruments that will be necessary. The *Fundament* consists in another glass, as figured in the margin, which will be walled in next to the other one in the same place in the oven, so that both heads come into the oven, and both necks stick out. There is also mercury in this glass, which captures and encloses the air inside, so that it can no longer condense or rarify, or the mercury follows it very closely, and betakes itself above or below the equilibrium, according to how the air dilates or condenses through the heat. Through this glass and the various movements of the mercury the control will be kept steady according to the will of the artist, and closes thus:

1. A bent cork rests upon the mercury, and goes out over the neck of the governing glass, and this cork thus follows the mercury. When the heat in the oven increases, then the cork rises somewhat upwards off the neck, but when it decreases, the cork goes back in again.
2. One must have a spoon with a special handle, which has approximately in the middle a small piece of iron in the form of a cross. With these axes, the spoon lies upon two raised plates, so that, when one part of the spoon goes upwards, the other goes down.
3. The handle must be fastened to the cork that lies upon the mercury with a screw that has its mother on the handle, and is fastened into the cork, and the spoon covers the airhole that governs the oven, and both this hole and the spoon are from brass or copper, so neatly filed and fitted together, that when the spoon lies upon the hole, the coals have no air, and they must therefore go out, and in this the entire control consists. Then when one has the oven at the desired degree, which the measurement lets you know, then very nimbly one must make it (although it is better to show this than to describe it) so that the cork lays outside the mercury in a position of equilibrium and the spoon also covers the hole neatly. As soon as the coals begin to go out, then the air in the controlling vessel condenses as well as in the other, and then they lay in one place over one another. When however the air condenses, then the mercury runs back and with it also the cork which lies upon it, as well as the handle of the spoon, and the handle goes downwards, then the spoon goes up from the airhole and gives the coals again air to burn, [and] should the coals go on too much and increase the heat, then the air in the glass dilates and pushes the mercury further, the mercury [pushes] the cork, and the cork [pushes] the handle of the spoon, and so the spoon again closes the airhole, and thus the oven can become neither colder nor hotter, for if it should become cold, then the spoon will open up, and should it become too hot, then it closes again, and it offers those who see it a very pleasant speculation.

In the glass AB of two parts AC which is attached to the other BE, observe that the line CD must go into the coals to the point D. Since the slightest air can go out through a joint, and it is impossible to stop it, therefore the joint must rest against the glass, rather than joint against joint. In order to attach the glasses together one takes first unspun flax, which is spread with the Hermetic Seal, and so that the glasses will bind one onto another, afterwards with a towel or linen band also tucked in around it. When the towel is dry, take common potter's glue, worked through sheep's wool without any other addition, with the corner over the band, and if that doesn't hold, then spread the dried glue with boiled glue, like the kind that plate-makers and tin founders use, as I finally had to spread mine before it would hold, since we did not give it enough time to really dry. The bulb of the vial must never touch anywhere except the stone upon which it rests, and therefore we have closed it approximately at the neck with glue.

JK is the *Vas judicatorium*, whose neck must be bent, [and] so that no material stays lying in the bulb, the neck must be very narrow, [and] one makes the oven hotter than one plans to use it for 2 days, and that the air will be emptied out of the glass HK, [and] when it has stood in this heat for 2 days, then one pours the mercury into the pot and lets the oven cool, and the mercury rises up.

(D. Reger has one now from a single glass. In one hole of the oven, the latter comes in, and in the other that is next to it, the former.

(On the hole D. Reger has a Perpendiculum of brass, that can be let go back and forth, and is screwed in tightly)

B. The Spoon

The neck above the oven

The Sustentaculum on the oven, where the axes lie.

Gotha Postscript

The Gotha manuscript is shorter, has slight differences of diction, but most importantly includes the following postscript, and is signed with an "N."

NB. H. Morian seel. gewesener Pfarrer zu Muÿden, welcher aus Curiosität Eÿer in diesem Ofen ausgebrütet, hat hierbeÿ notiret: Ich sage für meine Speculation, dass das Auge scheinl. ander bewegung des Löffels, mercken kann, so empfindl. ist der [air] und so hurtig folget eins auf das andere. Ich N. sage, dass das Glass A.B. wohl aus einem Stück, oder von einen phiol gebogen, das lutiren ersparet und der [mercurius], sowohl vor alss nach dem biegen, hinein gebracht werden könne: und wann Ich diesen Ofen gebrauchen solte, so gedächte Ich das Regimen über die aus dem Kaminn [?] in den Ofen gehende Röhre zu appliciren.

Note: Mr. Moriaen, a pastor at Muiden, who out of curiosity incubated eggs in this oven, noted here: I say for my speculation, that the eye can clearly see the movement of the spoon, so sensitive is the air and so quickly does one follow the other. I, N., say that the Glass A.B. can well be of a single

piece, or from a bent vial, so that the luting may be spared and so that the mercury may be put in from in front as well as from behind the bend. And when I use this oven, I thought I might apply the control through the pipe coming out of the chimney and into the oven.
N.