The Barometer, Signature Instrument of the Enlightenment

> „Göttingen, den 10. April 1769 um nach 11, Barometer Höhe 26 Zoll zehen Linien Pariser Fuß, Fahrenheitisches Thermometer 51° über 0, Wind, teuere Zeiten, schlechtes Essen."
>
> Georg Christoph Lichtenberg,
> Letter to his brother Ludwig Lichtenberg (Lichtenberg IV, 1994: 11)

Most scientific instruments perform their service without receiving much public attention. When they fall into desuetude, they are discreetly removed from the inventories to be remembered only by collectors and historians. Even when they are in active use, their name and specific purpose are usually just known to researchers working with them but unbeknownst to the general public. However, some devices are capable of transcending the boundaries of the academic fields they originated in. They manage, for a variety of reasons, to inspire the collective imagination and become social and cultural phenomena. The telescope is such a case, from Galilei's first use as an astronomical tool to current versions orbiting Earth and the Sun. The barometer, I would argue, had its heyday in the 18th century but has since lost its appeal to the general public. The device still performs important tasks in different shapes and forms: it plays its part in surface weather observations, has industrial applications, and consumer models can be found (admittedly, as vintage items) in many households. However, how many owners of those domestic barometers do utilize the instrument for its intended purpose, and how many would even know how to read barometric measurements properly? This was different 300 years ago. The newspapers featured weather reports with barometric data and little to no explanation of the numbers, indicating that their learned audience was familiar with air pressure units and their meteorological meaning. Even a cursory glance at sources such as diaries, letters, and even poetry provides plenty of evidence for the presence of the barometer in the collective psyche of the period.

The device has left many traces in philosophical and literary works of the 18th century—

Wittenbergisches

Wochenblatt

zum Aufnehmen der Naturkunde und des ökonomischen Gewerbes.

17 Stück, Freytags, den 29 April 1768.

Unter Churfürstlich Sächsischem gnädigstem Privilegio.

I. Morgen- und Abendbemerkungen der Luft.

Vor. Tage.		Schwere.		Temperat.		Feuchtigkeit.		Regen.		Winde.		Wetter.
☽ 23.	♄	27, 58.	7, 59	49/8.	52/2	13/3.	23/2.	0. 4)	9. 7	W. 4.	WSW. 4.	fr. 2. (reg. 1. fl. 2.
24.	☉	27, 66.	7, 72	47/5.	54/4	24/9.	22/1.	2.	(81.2	WSW. 1.	WgS. 3.	neb. fl. 2. (gew. r. 3. fl. r
25.	☽	27, 92.	7, 90	50/6.	55/9	2/0.	019/8.	4.	0	W. 5.	SW. 2.	klar 3. klar 2.
26.	♂	27, 75.	7, 81	54/0.	53/4	4/3.	05/1.	0. 1)	8. 0	WgS. 5.	W. 1.	fl. 1. reg.) klar 2.
27.	☿	27, 84.	7, 78	47/1.	47/8	044/2.	040/2.	0. 2)	21	WSW. 4. 5.	W. 2.	fl. 4. gr.) gew. fl. 2.
28.	♃	27, 85.	7, 87	43/8.	44/2	05/4.	047/2.	0. 11)	0	WSW. 1.	WNW. 3.	fr. 3. reg. 2. heiter
29.	♀	27, 91.	7, 79	37/7.	54/8.	020/9.	16/6.	0.	0	NgO. 1.	SW. 2.	heiter trübe 1.

Figure 1: *Wittenbergisches Wochenblatt*, April 29, 1768 (https://anno.onb.ac.at). 18th century newspapers started to print barometric records without further explanation, indicating that the readership was informed enough to interpret the data on their own.

take, for instance, the writings of Kant[1], Lichtenberg[2], and Goethe[3]. Furthermore, the barometer as well as other meteorological instruments became a decorative item for wealthy households, typically in designs more ornamental than functional (see fig. 4). The popularity and near-ubiquity had its semantic impact: It took some time to establish the designation ”barometer” (rather than ”Torricellian tube”, ”baroscope” or ”weather glass”, the name of its precursor) but the linguistic evidence suggests that the device and its purpose had become common knowledge in the early 17th century (among the educated class, I

[1]See, e.g., the *Reflexionen zur Metaphysik*: ”[...] ist aber die Einrichtung der maschiene so gemacht, daß sie auf gar keine einzelne, sondern auf einen Grund aller derselben unbestimmt angelegt ist, so ist die Zurichtung ein allgemeiner realgrund. e.g. so ist ein Barometer ein allgemeiner Luftmesser, und die Füsse eines Springers sind nicht auf die einzelnen Tänze, sondern auf gehen und tanzen überhaupt eingerichtet.” (Kant AA 17: 324) It is no coincidence that Kant takes the barometer as an example for a general purpose machine, a device with an inherent adaptability and an inherent openness to new use cases and novel epistemic approaches. In *Etwas über den Einfluß des Mondes auf die Witterung*, Kant refers to barometric measurements as support of a critical review of the popular hypothesis that the moon had a substantial effect upon the weather (Kant AA 08: 315-324).

[2]Both the *Sudelbücher* and Lichtenberg's correspondence offer insights into the difficulties meteorological enthusiasts encountered. Lichtenberg repeatedly explained to exasperated correspondents the reasons that their barometers did not work as expected: design faults, poor product quality, and lack of knowledge on part of the instrument owners (see, e.g., his letter to Franz Ferdinand Wolff with detailled instructions how to read the measurements correctly, including sketches and the algorithms to calculate the altitude, in Lichtenberg IV, 1994: 585-592). Lichtenberg, a professor of experimental physics at Göttingen, was taking note of new publications on the barometer. He recommended those he deemed accurate, remarked ironically on the state of knowledge, ”Wir haben, wo ich nicht irre, 17 Hypothesen über das Fallen und Steigen des Barometers” (Lichtenberg I 1994: 828f), and quipped about the contentious debate among his fellow scientists: ”Der siebenundachtzigjährige Hollmann und Senior der ganzen Universität wie er sich selbst nennt, hat kürzlich ein Buch über die Barometer und Thermometer drucken lassen, worin er einen ganz abscheuligen Ausfall auf Kästnern tut und ihm auf eine verdrüßliche Weise den freilich großen Mayer entgegensetzt und ihn dabei einen mathematischen Scharlatan und Mikromegas nennt. Die Orthographen und Wetterpropheten kriegen es auch recht derb zugezählt, und dieses, wie mich dünkt, nicht so ganz mit Unrecht.” (Lichtenberg 1994 IV: 514)

[3]See https://woerterbuchnetz.de/?sigle=GWB&lemid=B00409

should add)[4]. A further indicator for the widespread familiarity with the instrument and its mode of operation, is the figurative usage of the word barometer. As early as 1710 the anonymous author—later revealed as Richard Steele—of a satirical piece in *The Tatler* writes: "I have an engine in my study, which is a sort of Political Barometer, or, to speak more intelligibly, a State Weather-glass, that, by the rising and falling of a certain magical liquor, presages all changes and revolutions in government, as the common glass does of the weather."[5] German speakers adopt the metaphorical sense of the term during the 18th century.[6]

From its early days and particularly in the course of the 18th century, the barometer took on a sociocultural meaning. Empiricist philosophers in the 17th century and many proponents of the Enlightenment showed theoretical and practical interest in meteorological devices. This connection has been made in the research literature[7], and for the German physicist Johann Samuel Traugott Gehler, the barometer even represented a catalyst of profound epistemic change: Toricelli's invention, Gehler writes, contributed eminently to the downfall of the dated physics of the Scholastics: "Da die Erfindung des Barometers durch Toricelli im Jahre 1643 so viel zum Umsturz der alten scholastischen Physik beygetragen hat, so verdient ihre Geschichte hier umständlicher erzählt zu werden".[8] Gehler relies his assessment on the argument that the operating mode of the barometer implied the demise of the Aristotelian *horror vacui*-hypothesis[9]. Feijoo's *Teatro Crítico Universal* has a chapter on air pressure[10], and Gaspar Melchor de Jovellanos, key figure of the Spanish Enlightenment, used a barometer for his weather observations[11] while he was confined

[4]The semantic evidence varies by language, though. The *Dictionnaire de L'Académie française*, for instance, acknowledges the word «barometre» as part of the French vocabulary: https://portail.atilf.fr/cgi-bin/getobject_?p.1:2./var/artfla/dicos/ACAD_1694/IMAGE/. The historical corpus for Spanish CDH, on the other hand, has 1728 as earliest reference for the lemma «barómetro» (for the corpora references see **??**).

[5]The Tatler, August 22, 1710, https://mdz-nbn-resolving.de/details:bsb10616787_00035_u001

[6]The *Deutsches Wörterbuch von Jacob Grimm und Wilhelm Grimm* provides as example a quotation from Musäus' *Physiognomische Reisen* (vol. 4, 1778): "[..] daß der barometer meines humors, der bey empfang der depeschen auf böß wetter herunter gefallen war, wieder anfing zu steigen" (https://woerterbuchnetz.de/?sigle=DWB2&lemid=B00654)

[7]See, e.g., the fourth chapter, *Barometers of Enlightenment*, in Golinski 2007 (pp. 108-136) and also Golinski 1999.

[8]Gehler vol. 1, 1787: 237

[9]ibidem

[10]Feijoo 1769 [1728]: 217-225; The *Teatro Crítico Universal, o Discursos varios, en todo género de materias, para desengaño de errores comunes* (vol. I-IX, 1726-1740) was probably the most seminal work of the early Enlightenment in the Spanish-speaking world, with several reeditions during the 18th century (see https://www.cervantesvirtual.com/portales/benito_jeronimo_feijoo/su_obra_bibliografia_1/). On the role of instrumental meteorology in the Spanish Enlightenment see also Guijarro Mora 2005, Anduaga Egaña 2012: 29-74, and García Hourcade 2002.

[11]For a meteorological evaluation of Jovellanos' temperature and barometric measurements see Vaquero

in the Bellver fortress on the island of Mallora (which means that one of the early meteorological records in Spain was produced by a political prisoner). As in many diaries and letters of the time, the reading of meteorological measurements is a regular part of the daily record:[12]

Domingo, 28 de diciembre. – Misa y chocolate según costumbre, y después, Apéndice. A mediodía nos acompañó Carlos Masiá, hijo: comimos dátiles de Mahón, que regaló la señora Generala [María Antonia Escavias de Carvajal], y ostras de la costa de enfrente. Tarde: paseo con [Juan] Du Cros. Noche: Apéndice y lectura en Mariana. El día, bueno, aunque ya nebuloso, porque el barómetro baja.
Mañana.- 9,9 / 11,9. Nubes. E.
Mediodía.- Ídem / 12,1. Ídem. SO.
Noche.- 9,7 / 10,0.

Sunday, December 28. - Mass and chocolate as custom demands, and after that, Apéndice [a text he was working on]. At lunch, we had the company of Carlos Masiá, Jr.: We had dates from Mahón, a gift from Miss General [the wife of the colonel general of Mallorca], and oysters from the coast. In the afternoon a walk with [Juan] Du Cros. At night [work on] Apéndice, and reading Mariana.
The day was fine, although already foggy because the barometer is descending.
Morning.- 9,9 [barometer] / 11,9. [temperature] Cloudy. [East wind]
Noon.- Idem / 12,1. Idem. [Southwest wind]
Night.- 9,7 / 10,0.

What the new scientific instruments made possible was: To see the world differently, and, moreover, to see new worlds. This is a point frequently made by those who have engaged with the newly invented apparatuses. Robert Hooke, for instance, by then "Curator of Experiments" at the Royal Society,[13] wrote in the preface of his *Micrographia* (1665): "By the means of Telescopes, there is nothing so far distant but may be represented to our view; and by the help of Microscopes, there is nothing so small, as to escape our inquiry; hence there is a new visible World discovered to our understanding."[14] The essayist and magazine editor Joseph Addison[15] noted in a similar vein: "Thus are our Eyes become more penetrating by modern Helps, and even that Work which Nature boasts for her Master-Piece, is rendred more correct and finished."[16] Addison also composed a didactic poem about

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[12] Cuaderno duodécimo. Fragmento del cuaderno de Bellver. Por mano del amanuense de Jovellanos, Manuel Martínez Marina. Día 28 de diciembre de 1806, in: Jovellanos, Diario 3º, cuaderno 12, https://www.unioviedo.es/jovellanos/index.php/obras-completas/. Cf. Vaquero Martinez 2023: 25f on Jovellanos' instrumental measurements.

[13] https://makingscience.royalsociety.org/people/na8242/robert-hooke

[14] Hooke 2007: [iv]

[15] Jan Golinski has used some Addison pieces in *The Spectator* as evidence for the growing interest for weather and meteorology in Britain around 1700 (Golinski 2007: 58, 150f: More on and by Addison as essayist for *The Tatler* and *The Spectator* in Gigante 2008: 23-84.

[16] Addison 1727: 12

the barometer[17] (and was not the only one to do so[18]) and wrote a passionate endorsement of a "new philosophy" as opposed to the old scholastic way of thinking. Due to authors like Descartes and the use of the new scientific instruments, he hoped, the world would be experienced in an entirely novel and unprecedented way:

> «This Philosopher [i.e., Descartes] scorned to be any longer bounded within the Straights and Chrystalline Walls of an Aristotelick World; No, his Delight is to search the Regions above, to discover new Suns, and new Worlds, which lay hid amongst the Stars; his Satisfaction is to view that large Kingdom of Air amidst the unfixed Stars, and Lands that pass die milky Way, and more accurately measure this vast Machine, a Machine fit for Mankind to philosophize on, and worthy of the Deity, that first framed it. [...] We no longer pay a blind Veneration to that barbarous Peripatetick-Jingle, those obscure Scholastick Terms of Art, once held as Oracles, but consult the Dictates of our own Senses, and by late invented Engines force Nature her self to discover plainly her most valued Secrets, her most hidden Recesses.»[19]

For Addison and likeminded intellectuals the new optical devices[20] did not only herald a fundamental epistemological shift in the scientific approach to the world, they were as well the means to an ontological change of how we perceive the world around us.[21] The antagonism between the "new" philosophers and the "old" ones like Aristotle (whose books should be in Addison's opinion "Food only for Moths and Worms"[22]) is a recurrent theme in the early literature on scientific instrumentation. Robert Hooke, for instance, writes defiantly in the preface of *Micrographia* (1665): "The truth is, the Science of Nature has been already too long made only a work of the Brain and the Fancy: It is now high time that it should return to the plainness and soundness of Observations on material and obvious things."[23] The rivalry between traditional Scholasticism and its contenders was not just an

[17] Addison 1698: 75-79.

[18] See this recent research project on scientific poetry: https://scientificpoetry.org/about

[19] Addison 1727: 11-13. Addison wrote this initially 1693 as an Oxford student under the title *Nova philosophia veteri praeferenda est*, the 1727 print edition from which I am quoting, is an English translation, probably by Addison himself. For more on the original text in Latin, see https://wiki.uibk.ac.at/noscemus/Nova_philosophia_veteri_praeferenda_est.

[20] As historians of science have shown (see, e.g., Schaffer 1998), for quite a few scientists and philosophers the technologically enhanced human senses were not entirely new faculties. To their mind, the newly invented contrivances were, in fact, a recapturing of lost prelapsarian abilities of humankind. Hooke alludes to this in the opening lines of *Micrographia*: "By the addition of such artificial Instruments and methods, there may be, in some manner, a reparation made for the mischiefs, and imperfection, mankind has drawn upon it self [...]." (Hooke 2007: [i]). As Joseph Glanvill (*Vanity of Dogmatizing*, 1661) put it in a nutshell, Adam "needed no spectacles" (Glanvill, quoted in Hamou 2022: 343).

[21] Similar or related to Max Weber's notion of the "disenchantment of the world" by scientific thought ("Entzauberung der Welt").

[22] Addison 1727: 16

[23] Hooke 2007: [v]

academic turf war: In conservative countries like Spain, such disputes were also politically charged (see my posts https://ilinx.at/posts/read-like-an-inquisitor.php and https://ilinx.at/posts/read-like-an-inquisitor.php).

When the telescope and the microscope enhanced the visual faculty, so was this an augmentation of the human sensory system. The barometer, in contrast, made something else possible: seeing the future by technical means. In an erudite comparison by Thomas Loup: The new apparatus will foretell the coming weather with a reliability the prophecies of Delphi and all the other ancient oracles could never have achieved.[24] "The sky may be obscured by dark clouds, giving every appearance of heavy rains, writes Addison in his poem *Barometri Descriptio*, and gives then the advice: don't believe your eyes, trust the instrument instead.[25]

Physicians as early adopters of the barometer

The predictive power, although frequently overrated (especially on part of instrument sellers), suggested multiple use cases for the new apparatus. When early advocates of the barometer praised the potential benefits of the instrument, they cited its practical usefulness with farmers, travelers, and the military as preferred examples. There are two professions, however, that stand out as "early adopters" of the barometer and other meteorological contrivances: physicians and mariners. Both had an occupational interest in the weather and both had tried for some time to make sense of the weather by reading signs in the sky. Their constant search for prediction tools is a through line that somehow connects astrology and the barometer. The former was the prevalent forecasting technique prior to the introduction of the barometer and both astrological and instrumental methods coexisted for quite some time.[26]

The sheer number of physicians pioneering the use of the barometer is remarkable. Robert Fludd's writings on the use of the weather glass as a diagnostic tool were widely read among physicians all over Europe (→ Chap. 2). Perhaps even more impact had the first broadly circulated call to collect meteorological observations: The trained physician James Jurin (better known for his novel statistical approach to smallpox inoculation[27]) issued in his capacity as the secretary of the Royal Society invitation to submit meteorological

[24] Loup 1749: 208

[25] «Si vitrum negat, & sudum promittit apertum, / Audax carpat iter nimbo pendente viator.» / *If the [weather-]glass says otherwise, and promises fine weather and open air, the courageous traveller sets off under the hovering clouds.* (Addison 1698: 77). Likewise, Thomas Loup's recommendation for the traveler: disregard the thundery clouds, as terrifying they may look, and just pay attention to the motions of the mercury in the barometer (Loup 1749: 198).

[26] See, e.g., Robert Fludd who thought the motion of the mercury in the weather glass was connected to the human body as well as to the universe, an idea rooting alchemical and astrological traditions: → Fig. 5.

[27] See Andrea Rusnock study of Jurin's role in the public inoculation debate in the 1720s: Jurin provided

records to the *Philosophical Transactions*. Jurin made recommendations for the equipment and provided a template for the observational records (see Fig. **??**). The response was considerable in numbers, and the quantity of records posed a challenge seemingly too ambitious for the Society's capacities[28] Weather observing enthusiasts distributed Jurin's *Invitatio ad observationes meteorologicas communi consilio instituendas* (Invitation to set up meteorological observations based on a common plan) in other journals, as did, for instance, Jacob Leupold in 1726, delivering a German translation (*Jurini Einladungsschrifft zu denen meteorologischen Observationibus*).[29] Among those who sent own records in response were also many physicians[30]

Physicians were among the professions that had already conducted meteorological observations prior to the invention of weather glass and barometer. In their understanding, the weather had a heavy bearing on the human body. Their explanations for this connection are deeply rooted in the early modern interpretation of Hippocratic and Galenic medicine as well as in medical astrology.[31] Proponents of this approach are often subsumed under the so-called "iatro-mathematical" (or "iatro-mechanical") school of medicine – "iatro" derives from the Greek term for physician[32] while "mathematical" means here (as it often does in the early modern period) "astrology".[33] As far as medical meteorology is concerned, the use of Hippocratic concepts and astrology persisted well into the instrumental era and influenced the early usage of the barometer (see the post `https://ilinx.at/posts/madrid1737.php` on the observational project of physicians in Madrid).

The second important group of early instrument adopters are seafarers, and more precisely,

convincing arguments in favor of inoculation (Rusnock 2002: 43-70). Rusnock has also a section on Jurin and medical meteorology (Rusnock 2002: 113-116).

[28] See Jan Golinski's summary: "Most of them languished unpublished in the society's archive, as Jurin found himself submerged in data and unable to create a comprehensive synthesis". (Golinski 2007: 55) See also Golinski 142ff. and 193f. on individual responses.

[29] Leupold 1726: 296 (recte: 306)

[30] Just to name those mentioned in this paper: Lynn 1741, Lining 1743; the first instrumental observations on the Iberian Peninsula were conducted by the Portuguese court physician Diogo (Samuel) Nunes Ribeiro (Domínguez-Castro/Trigo/Vaquero 2013: 444-446).

[31] The Yale University Library's online exhibition *Medical Astrology: Science, Art, and Influence in early-modern Europe* provides an overview on the subject: `https://onlineexhibits.library.yale.edu/s/medicalastrology/page/introduction`

[32] LSJ: «ἰατρός» "one who heals, physician or surgeon"

[33] Early modern "scientific" astrology was largely computation and hence considered a subfield of mathematics. See, for instance, the title of Joseph Moxon's successful textbook, *Mathematicks made Easie: or, A Mathematical Dictionary, Explaining the Terms of Art, and Difficult Phrases Used in Arithmetick, Geometry, Astronomy, Astrology, and Other Mathematical Sciences* (1679). Astrological almanacs predicted droughts, floods, untimely frost, or the peril of war; due to their popularity they had a regular section in book catalogs such as the *Messkataloge* for the Frankfurt book fair (see `https://staatsbibliothek-berlin.de/die-staatsbibliothek/abteilungen/handschriften-und-historische-drucke/sammlungen/historische-drucke-ab-1501/bestaende/messkataloge` & `https://lbssbb.gbv.de/DB=1/SET=7/TTL=1/MAT=/NOMAT=T/REL?PPN=096632321`).

navigators of long-distance voyages. They are less present in the publications of the learned societies than the medical authors, but they had accumulated much practical knowledge on the weather, and it was the navy academies that incorporated the training in meteorological instruments in their curricula towards the end of the 18th century. Much like the ”iatro-mathematicians”, they had resorted to astrology for weather forecasts before they turned to the novel devices. To cite an example that occurred during a quite consequential voyage: The logbook of Cristóbal Colón, in English known as Christopher Columbus, explains his decision to delay the departure from a bay on the island of Hispaniola:

> «Domingo, 13 de Enero [1493]. No salió d'este puerto por no hazer terral con que saliese. Quisiera salir por ir a otro mejor puerto, porque aquel era algo descubierto, y porque quería ver en qué parava la conjunción de la luna con el sol, qu'esperava a 17 d'este mes, y la opposición d'ella con Júpiter y conjunción con Mercurio y el sol en oppósito con Júpiter, que es causa de grandes vientos.»[34]
>
> *He did not leave the port because there was no land breeze to sail off. His intention was to move to a different port because this was one that was somewhat exposed. Also, he wanted to wait for the conjunction of the moon with the sun which he expected for the 17th of the month, and then the opposition of the moon to Jupiter, the moon's conjunction with Mercury and the sun's opposition to Jupiter which causes high winds.*

I should add that astrology was just one of several techniques in the toolbox of early modern navigators. They also used all kind of visual clues in the sky and the ocean to predict changes of the weather, and in order to set and hold to a course, navigators resorted to astronomical reference points such as star constellations or the solar zenith angle.[35]

The many meteorologies of the early modern period

In his 1690 book *Libra astronómica y filosófica*, Carlos de Sigüenza y Góngora, royal cosmographer and professor of mathematics at the University of Mexico, expressed nothing but disdain for meteorology. The very idea, he quips, of meteorologically predicting if it will rain, if it will be cold or hot, and so forth would be just ridiculous.[36] If we keep reading, however, it becomes clear what he means by ”meteorology”: it is just another name for astrology, and the ridiculous idea refers to the assumption that one could predict the

[34] Colón 2003: 194

[35] See as an example Pedro de Medina's *Arte de navegar*, a textbook on longe-range navigation, originally written as a manual for the helmsmen (*pilotos*) of the transatlantic cargo ships. De Medina's book displays a nautical skillset comprising Pre-Copernican astronomy, astrology, and meteorology. The latter focuses, as one might expect, on winds in relation to sailing and sea currents (de Medina 1545).

[36] «Luego si para pronosticar en lo meteorológico de una cosa tan ridicula, como es si ha de llover o no, si hará frío o calor, etc. [...].» (Sigüenza y Góngora 1984: 173)

weather by observing the motions of the stars.[37] He then makes the case against astrological meteorology with a simple but lucid argument, putting the American topography into play: How could the configuration of Mars, Venus, or Jupiter affect the weather when the flow of the winds is clearly determined by mountain structures like the Andes—and what is the use of astrology, he then asks, if it is not applicable to all climates and latitudes?[38] In the 1730s, the art of weather prediction was still heavily associated with astrology which may be the reason that Fernández Navarrete, in charge of Spain's first instrumental observations, did not use the term "meteorology" at all (he spoke of "barometric" observations instead, see fig. **??**).

However, the prevalent meaning of "meteorology" in the early modern period was derived from Aristotle's book of the same name. His *Meteorologica* (Μετεωρολογικά) treats of all kinds of things in the skies, comets, and the Milky Way included[39] — which is only concordant with the original meaning of the Greek term μετέωρος, "raised from off the ground, high in air"[40]. A typical example of early modern Aristotelian meteorology would be Martin Lister's explanation of the trade winds, published in the 1684 volume of the *Philosophical Transactions*: "Among the known Sea Plants, the Sargosse, or Lenticula Marina, is not to be forgot; this grows in vast quantities from 36 to 18 degrees north latitude, and elsewhere on the deepest Seas. And I think [...] from the daily and constant breath of that Plant, the Trade or Tropick Winds do in great part arise: because the matter of that Wind, coming (as we suppose) from the breath of only one Plant, it must needs make it constant and uniform."[41]

The evidence in encyclopedias and journals for the learned audience indicates that in the second half of the 18th century "meteorology" converged semantically with our current understanding of the term. However, the association with questionable practices had not completely disappeared. Johann Christoph Heppe, author of *Kurze Beschreibung der Barometer und Thermometer auch anderer zur Meteorologie gehörigen Instrumenten* (1776), felt the need to defend meteorological observations against the suspicion of belonging to the dark arts or being an ilicit activity: "Die Zeichendeuterkunst ist eben keine

[37] «[...] hablo de la meteorología y astrología racional no de la judiciaria, por cuyo medio pronostican guerras...» (Sigüenza y Góngora 1984: 173). The distinction between meteorology, i.e., "rational astrology" and "judicial astrology"—the latter intended for the prediction of wars—, had legal implications at the time but can be ignored in the context of this paper

[38] «Por ventura no se expondría a errar el que en esos llanos, por haber advertido en el cielo configuración que denote lluvias y tempestades, las pronosticase, cuando allí jamás esto sucede, aunque sea en las tortísimas aperciones de Marte y Venus, y de Mercurio y Júpiter, pues la disposición de los montes que impiden a los vientos se opone a todos los influjos de los cielos? Luego aunque fuera verdad haber hecho observaciones el mismo Adán y que se conservasen hasta estos tiempos, de qué le servirían en general a la astrologia, no siendo acomodables a todos [los] climas y paralelos.« (Sigüenza y Góngora 1984: 173

[39] Meteor. lib. I, and lib. IV-VIII (Aristotle 1952: 29-69)

[40] LSJ: «μετέωρος» (metéoros)

[41] Lister 1684: 494; Lister draws here from *Meteor.* lib. II,iv where Aristotle dismisses the idea that wind could be caused by motion of air and suggests instead "exhalations" as cause of wind (Aristotle 1952: 167ff)

so schädliche, unerlaubte und bestrafenswürdige Kunst, als sich viele einbilden, und allgemein glauben. Das ist, höre ich schon im Geiste viele meiner Leser sagen, ein sauberer Anfang; wenn es so fortgehet, werden wir wol nichts als gottlose Sachen zu lesen kriegen. [...] Unter die erlaubte Zeichendeuterey rechne ich nun auch die Kunst das Wetter zu prognisticiren."[42] The academic understanding of the word—not necessarily its meaning in common parlance—had become aloof from any astrological notions. Meteorology had become a discipline based on the principles of mechanics and instruments offered the opportunity to study the complex machinery in the skies. As Lichtenberg put it in his both sobering and optimistic assessment of the state of meteorology in 1778: "Trotz den Bänden meteorologischer Beobachtungen ganzer Akademien, ist es noch immer so schwer vorherzusagen, ob übermorgen die Sonne scheinen wird, als es vor einigen Jahrhunderten gewesen sein muß, den Glanz des Hohenzollerischen Hauses vorauszusehn. Und doch ist der Gegenstand der Meteorologie, so viel ich weiß, eine bloße Maschine, deren Triebwerk wir mit der Zeit näher kommen können."[43]

The semantic shifts of "meteorology" in the early modern period (and the corresponding epistemic changes) illustrate how history of science entails the study of historical semantics (or, to use the more precise German term *Begriffsgeschichte*).[44] They also indicate the conceptual changes in an emerging field of science that would eventually result in the formation of an academic discipline of its own. This was, however, a heterogeneous process that played out over the better part of the 18th century. The advent of instrumental meteorology does not equate with a swift establishment of "modern" meteorology. Some instrument users interpreted the measured data according to early modern knowledge systems such as astrology, alchemy, or Hippocratic medicine; others welcomed the devices as a means of contending against precisely those notions which they deemed obsolete. The early modern history of instrumental meteorology is populated by different, sometimes competing disciplines, by learned enthusiasts and established scholars alike. There was no rapid Kuhn-like paradigm shift. Instead, there appear to be many blurry lines and, to borrow a phrase coined by Ernst Bloch, a period of *Gleichzeitigkeit des Ungleichzeitigen*.

A Social History of Air

Kant's description of the barometer as *allgemeiner Luftmesser*[45] makes particularly sense when read in context of the epistemological transformations the field of physics underwent

[42] [Heppe] 1776: 3, 7

[43] Lichtenberg 1994c: 266

[44] Ernst Müller and Falko Schmieder have produced a survey examining the manifold approaches within the broad field of Historical Semantics (Müller/Schmieder 2016). Even more pertinent to history of science is *Begriffsgeschichte der Naturwissenschaften. Zur historischen und kulturellen Dimension naturwissenschaftlicher Konzepte* by the same authors (Müller/Schmieder 2008).

[45] Kant AA 17: 324 (see above)

in the course of the 18th century. This also changed what was understood by ”air” and ”atmosphere”. As Lichtenberg put it in a fictitious monologue given by the 18th century about the scientific achievements during its tenure, ”statt einer einzigen Luft, die meine Vorfahren kannten, zähle ich dreizehn Arten”.[46] The new instruments convey also an entirely novel comprehension of the air: „Die eigentliche Feuchtigkeit, das ist, die kleinern unempfindlichen Wasserdünste der Luft anzugeben, hat man in neuern Zeiten die sogenannten Hygrometer erfunden, die deswegen billig den Namen Feuchtigkeitsmesser führen können. Die Luft ist nämlich die meiste Zeit mit vielen kleinen wäßrigen Theilen erfüllet, die man niemals würde bemerken können, wenn man mittelst dieser Werkzeuge nicht die Wirkungen ihres Daseyns spürete.“[47] Then there was the phlogiston eudiometer which in hindsight looks like a quaint contraption—a device measuring a substance that did not exist—it is, however, an example of the ongoing efforts to understand the surroundings by means of technology.[48]

For some, the new insights meant that the atmosphere was now perceived as a vulnerable matter, potentially endangered by the very scientists studying its composition: „Es wäre doch möglich, daß einmal unsere Chemiker auf ein Mittel gerieten unsere Luft plötzlich zu zersetzen, durch eine Art von Ferment. So könnte die Welt untergehen“, Lichtenberg notes down in his *Sudelbücher*[49]; Jean Paul adapts the idea in *Schmelzles Reise nach Flätz* and imagines a rogue chemist in the recently established Australian penal colony who alters the atmosphere in a cataclysmic way:

> «Ach, ja wahrlich! Da die Erdkugel in der größern Luftkugel eingekapselt steckt: so erfinde bloß ein chemischer Spitzbube auf irgendeiner fernsten Spitzbubeninsel oder in Neuholland ein Zersetz-Mittel für die Luft, dem ähnlich, was etwa ein Feuerfunke für einen Pulverkarren ist: in wenig Stunden packt mich und uns in Flätz der ungeheuere herschnaubende Weltsturm bei der Gurgel, mein Atemholen und dergleichen ist in der Erstick-Luft vorbei und alles überhaupt - Die Erde ist ein großer Rabenstein mit Galgen geworden [..].»[50]

[46] Lichtenberg 1994 III: 63; See, e.g., the different categories in Gehler's *Physikalisches Wörterbuch*: ”Gas, atmosphärisches Aeir, gemeine Luft, atmosphärische Luft [..]” (Gehler vol. 2, 1789: 353-361).

[47] *Wittenbergisches Wochenblatt*, January 22, 1758 (ANNO)

[48] See the description of the eudiometer in Gehler's *Physikalisches Wörterbuch* (1789): ”Ein Werkzeug, welches dazu dienen soll, die Güte oder Salubrität der Luft zu prüfen, d.i. anzuzeigen, in wie weit sie mehr oder weniger zum Einathmen dienlich, mithin für die Erhaltung der Gesundheit mehr oder weniger heilsam sey.” (Gehler vol. 2, 1789: 89), and *Luftgüteprüfungslehre für Aerzte und Naturfreunde* by the Austrian chemist Johann Andreas Scherer which is based on the same idea that a hypothetical combustion catalyst called ”phlogiston” could affect health as an air pollutant (Scherer 1789).

[49] Lichtenberg 1994 II: 460 (Heft K,334, 1793-1796); less dramatically, but in a similar vein: „Unsere Chymie hängt ab von der Schicht der Dunstkugel, worin wir leben, ihrem Druck und ihrer Qualität. Ihre Bestandteile sowohl, als die der Materien, die sie aufnimmt, vorzüglich des Wassers, mischen sich in alles.“ (Lichtenberg 1994 III: 107)

[50] Jean Paul 1996: 65

The paradigm shifts with respect to the composition and mechanics of the atmosphere had fundamental implications for the usage of the barometer. At the onset of the 18th century, barometric measurements were seen as a fairly reliable forecasting tool, based on the suggestion of a plain connection between air pressure and the imminent weather conditions, which was shown, by practical experience with instrumental measurements, to be overly optimistic. The serendipitous discovery of the dependence of air pressure on the altitude turned the barometer into a multipurpose device, but its deployment as an altimeter (which appeared to be quite popular among its learned users) required complex calculations.[51] As pointed out by Bachelard[52], the detection of atmospheric electricity added a further layer of complexity and made the barometer a sensor device for atmospheric charges. On the face of it, the barometer still displayed units of air pressure but the phenomena the instrument was measuring, had become increasingly complex and intricate[53]

The early advocates of the barometer (and, unsurprisingly, the instrument makers) entertained the idea that anyone with a barometer could forecast the weather on their own. By the end of the century, instrumental measurements were less seen as the final result of an observation, but rather as an intermediate step in research, as data that had to be interpreted and in many cases combined with other data for further calculations.[54] That required expert knowledge and access to high-quality equipment, which increased the significance of funding. The weather enthusiasts of the early instrumental period who hoped to predict the weather by taking a glance at the barometer were proven wrong, and towards the end of the 18th century the weather and its forecasting had become the prerogative of the emerging field of meteorology.

Makers and Markets

Say, you live around 1770 and want to purchase a barometer. What would your options be? Well, that depends primarily on your budget. If you are the English king (which may not be

[51] See, for instance, the sample calculations in Lichtenberg IV, 1994: 623, and [Heppe] 1776: 177-199; See also Shuckburgh 1777 (fig. **??**).

[52] Bachelard 1986: 211 (see above)

[53] See, e.g., Lichtenberg's proposal to use primitive weather balloons to explore the upper aerial strata in which he describes the atmosphere as the scene of complex processes: „Wird man dadurch Riesen-Schritte in der Kenntnis unserer Atmosphäre tun, Abnahme ihrer Dichtigkeit, Wärme, Feuchtigkeit, Ab- oder Zunahme der Elektrizität der Luft, die Höhenmessungen durchs Barometer, die Lehre vom Schall und dessen Fortpflanzung, die von der Refraktion, von Bewegung der Körper in elastischen Mitteln. Kenntnis der Ebbe und Flut der Luft; Kenntnis der in großen Höhen zu vermutenden Passatwinden. Die Untersuchungen des Nordlichts, der Lichtstreifen, die durch keine Drachen erforscht werden können, der magnetischen Kraft, der Entstehung des Hagels, des Schnees etc. werden unendlich gewinnen." (*Vermischte Gedanken über die aerostatischen Maschinen* (1783), Lichtenberg 1994 III: 69)

[54] I am strictly referring to scientific use cases. Vendors still promoted barometers as trustworthy prediction tools: see, e.g., Jacob Hemmer's scathing criticism of dishonest and greedy manufacturers.

a particularly desirable thing because then you would be ”Mad King George”), you could afford the finest and most expensive apparatus, manufactured by the famous horologist Alexander Cumming (see Figure **??**). According to records from the Royal Archives, Cumming was paid £1,178 for the barograph with an additional annual remuneration for the maintenance of the device.[55] To translate that sum into today's money: That purchase price would now have a value of approximately £200,000[56]. A probably better way of comparison, though, is the purchasing power of the 1760s: The luxury barometer cost as much as 171 horses or 252 cows or 11,780 days of wage for a skilled tradesman[57].

The less affluent had to accommodate the options at the lower end of the price range, e.g., to buy individual parts and piece them together, as the Danish astronomer Thomas Bugge did when he traveled to London in 1777 to visit the workshops of several renowned intrument makers[58]. Fortunately for historians of science, Bugge kept a record of his travel expenses, including the purchases of books and instruments. He spent a total of £88 4s for about 50 items of scientific equipment, among them a receiver for mercury (10s), a receiver with a barometer tube (10s), and a glass tube for a barometer (15s).[59] In today's money, this would amount to a total of roughly £12,300 while the 10 shillings —- or half a pound in the pre-decimal coinage system —-equate to approximately £70.[60]

The booming trade in barometers and other measuring devices developed, against the backdrop of the emerging consumer society in the 17th and 18th centuries, the characteristics of a diversified and international market. Specialized production[61], the occupation of market niches[62], and even advertising[63] and branding[64]. By the 1760s, English instrument

[55] See the description provided by the Royal Collection Trust: https://www.rct.uk/collection/2752/barometrical-clock

[56] Inflation calculator of the Bank of England https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator

[57] National Archives: Currency converter 1270–2017 https://www.nationalarchives.gov.uk/currency-converter/

[58] Such as the aforementioned Alexander Cumming who, according to Bugge, had put his very own observatory on the rooftop of his house, cf. Bugge 2010: 87

[59] See appendix 4, Bugge 2010: 191-196.

[60] Inflation calculator of the Bank of England https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator

[61] According to Nicholas Goodison, at the turn of the 18th century the Londoner John Patrick became the first instrument maker to specialize solely in barometers (Goodison 1968: 178; Golinski 2007: 122f). Golinski (2007: 123) has a reproduction of John Patrick's trade card (1710).

[62] The second edition of John Harris' *Lexicon Technicum* shows the beginning diversification in terms of construction types and purpose: In addition to the ”common barometer” (i.e., the original Torricellian model), there are new builds like the wheel barometer, and equipment for special tasks such as portable models and a marine barometer (Harris 1708: 'Barometer')

[63] According to Jan Golinski advertising for barometer started as early as 1677 (Golinski 2007: 122) whereas the first advertisement for its precursor, the weather glass, was printed in 1631 (Golinski 2007: 112).

[64] Instrument maker put conspicuous stamps, signatures, and initials on their products, see the numerous

makers reacted to the growing demand for barometers and scientific equipment with the introduction of semi-industrialized workshops[65]; by that, they could produce for foreign markets as well (a visual indication of this development was the barometer with displays in different languages, mostly English and French)[66]. The preferred adjective to refer positively to an instrument maker was "curious", which had then connotations like skillful and precise[67]. This was probably not a fitting description for the vast majority of manufacturers, given that poor quality was a common complaint among barometer users. Especially, off-the-shelf devices were poorly built and lacked a proper calibration. Therefore, it was not uncommon for the authors to give cautionary advice for prospective buyers. The entry for "Barometer" in Krünitz's *Oekonomische Encyklopädie* (1774) gives the following recommendations:

> «Bei dem Einkauf der Barometer hat man auf folgende Eigenschaften zu sehen. Man mus zuvörderst die Rohre untersuchen, ob sie aller Orten gleichweit, stark und ganz sey. Hernach, ob das unten befindliche Gefäßlein oder Kölblein nach seinem innern Raum 8 bis 10 mahl weiter sey, als die Weite der Rohre ist. Ferner hat man das Quecksilber zu betrachten, ob es allenthalben in der Röhre dicht auf einander liege, oder ob Luft dazwischen befindlich sey, die besonders gern an den Seiten zwischen der Röhre und dem Quecksilber hangen zu bleiben pflegt; hauptsächlich aber, ob nicht zu oberst über dem Quecksilber Luft zurückgeblieben sey? Das leztere kann man erfahren, wenn man das Barometer langsam und gelind neiget, und zusiehet, ob auch das Quecksilber völlig in das obere Ende der Röhre laufe. Wofern nun alle diese Umstände sich richtig befinden, so kann das Barometer richtig seyn, wenn nur auch der Zettel, worauf das Steigen und Fallen verzeichnet ist, an dem rechten Ort der Höhe angemacht ist.»[68]

A consequence of the "imperfections of the common barometers" (to quote the title Henry Beighton chose for his paper in the *Philosophical Transactions*, 1738) was a bad "usability". Perhaps the main problem with barometers: They broke. Continually. There are many accounts of shattered glass tubes or entire devices split into pieces. Portable barometers——large, bulky, and fragile implements—were particularly accident prone (see Fig. 2). Joseph August Schultes, professor of botany and chemistry at the University of Kraków, who wanted to measure the elevations of the Carpathian Mountains, describes the ordeal of using a barometer in the backwoods of the Austrian empire: "Mein Reise-

examples in Beretta/Brenni 2022 and Goodison 1968.

[65] Goodison 1968: 51

[66] Goodison 1968: 193; Goodison has several examples of such "bilingual" models, e.g., a pillar barometer by John Patrick with an "English" and a "French" side (Goodison 1968: 183)

[67] OED/Historical Thesaurus: «curious», "minutely accurate, exact, precise" (1614–1825); "ingenious, skillful, clever, expert" (1489–1782)

[68] Krünitz vol. 3, 1774/1782: 548-558

barometer zerbrach auf meiner letzten Reise, und in Krakau war Niemand, der ein gutes Barometer verkaufte oder besässe. Hr. Bergrath Hacquet vertraute mit das seine, um es auszukochen; aber in dem Augenblicke, als ich diese beschwerliche Arbeit begann, machte ein kalter Luftstrom die Röhre springen und ich musste also meine Reise ohne Barometer antreten."[69]

In addition to low-quality consumer devices, there were also instrument makers who excelled as inventors. The learned literature of the time shows a tendency to misrepresent their role in favor of scholars and "gentlemen scientists". The *Royal Society of London* famously disregarded the salaried class as witnesses of experiments based on the argument that only financial independence would guarantee an impartial judgment.[70] While some authors (including fellows of the RS) acknowledged the technological improvements introduced by craftspeople[71], the sources generally display an incomplete picture regarding the question who was driving the innovation. Something published as a new finding might already have been part of the "implicit knowledge"[72] of the manufacturers. Georg Christoph Lichtenberg describes such a case in a letter to Johann Heinrich Merck in 1786: "Mich wundert in der Tat, daß Herr Deluc so viel Wesens von Klipsteins Anblasen durch Wasserdämpfe macht, die Barometermacher haben dieses längst gewußt, es wird bloß Luftzug befördert, aber nicht neues Feuer erzeugt. [...] Wenn wir Feuer anblasen, so tun wir dieses auf ähnliche Weise durch Hinzubringen von fixer und phlogistischer Luft aus den Lungen. Der Barometermacher weiß aber gar wohl, daß Dämpfe keine solche Hitze geben wie der Odem, weil in letzterem allezeit noch eine Beimischung von reiner Luft ist."[73] John Patrick, *Rules and Observations on the Various Rising and Falling of the Mercury: To Foreknow the Weather by the Baroscope*; Leaflet London 1692; This simple set of rules (apart from being smart marketing) overstates the reliability the early barometers were capable of (Patrick 1692). Shuckburgh1777-Savoy-Mountain-Map.png, The barometer turned altimeter: Measuring the Savoy Mountain Massif (Shuckburgh 1777).
Ion Mihailescu, Simon Dumas Primbault and Jérôme Baudry: Science on the Summit: Exploring Scientific Tourism Through the Lens of Eighteenth Century Mountain Ascents. https://doi.org/10.4000/rga.10265

[69] Schultes 1807: 102

[70] See Steve Shapin: "Unfree men were those who lacked discretionary control of their own actions. Technicians, for example, belonged to this class-the class of servants-because their scientific labor was paid for." (Shapin 2010: 79)

[71] In a paper published in the *Philosophical Transactions*, Henry Beighton (Beigthon 1738) praised a novel barometer developed by the instrument maker Charles Orme (see figure **??**. Stephen Gray, an "amateur instrument maker" (Goodison 1970: 221), was accepted as fellow of the Royal Society (RFS) and was awarded a prize for his contributions (Mills 2020). John Harris' *Lexicon technicum* (1708) also cites examples of technological improvements by instrument makers (Harris 1708: 'Barometer').

[72] I am using the term—which derives of course from Michael Polanyi's concept of "tacit knowledge"—in a broad sense.

[73] Lichtenberg 1994 IV: 685f

Figure 2: Traveling salesman selling barometers in Hamburg, copperplate by Christoffer Suhr, in *Der Ausruf in Hamburg*, 1808: "Da es fast in allen Ständen so viel Glauben gefunden hat, und gutes Wetter ein so allgemeines Bedürfniß ist, so ist der Absatz sehr stark, aber auch die Güte der Instrumente sehr verschieden. Ein recht gutes Barometer kann nicht wohlfeil, und ein wohlfeiles nicht gut seyn. Der gewöhnliche Standort ist bey der Börse um die Börsenzeit, oder auch bei den Vorsetzen, wo die Schiffer die besten Kunden sind [...]." (Suhr 1808: 115f; Plate 88)

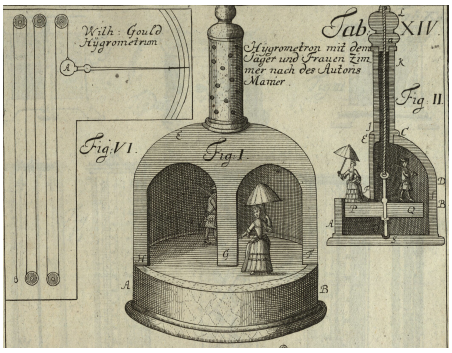

Figure 3: Leupold 1726

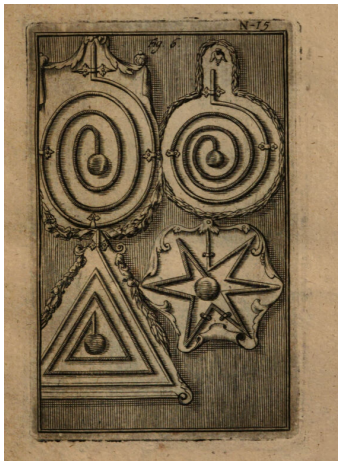

Figure 4: Measurement devices as design object (d'Alencé 1688)

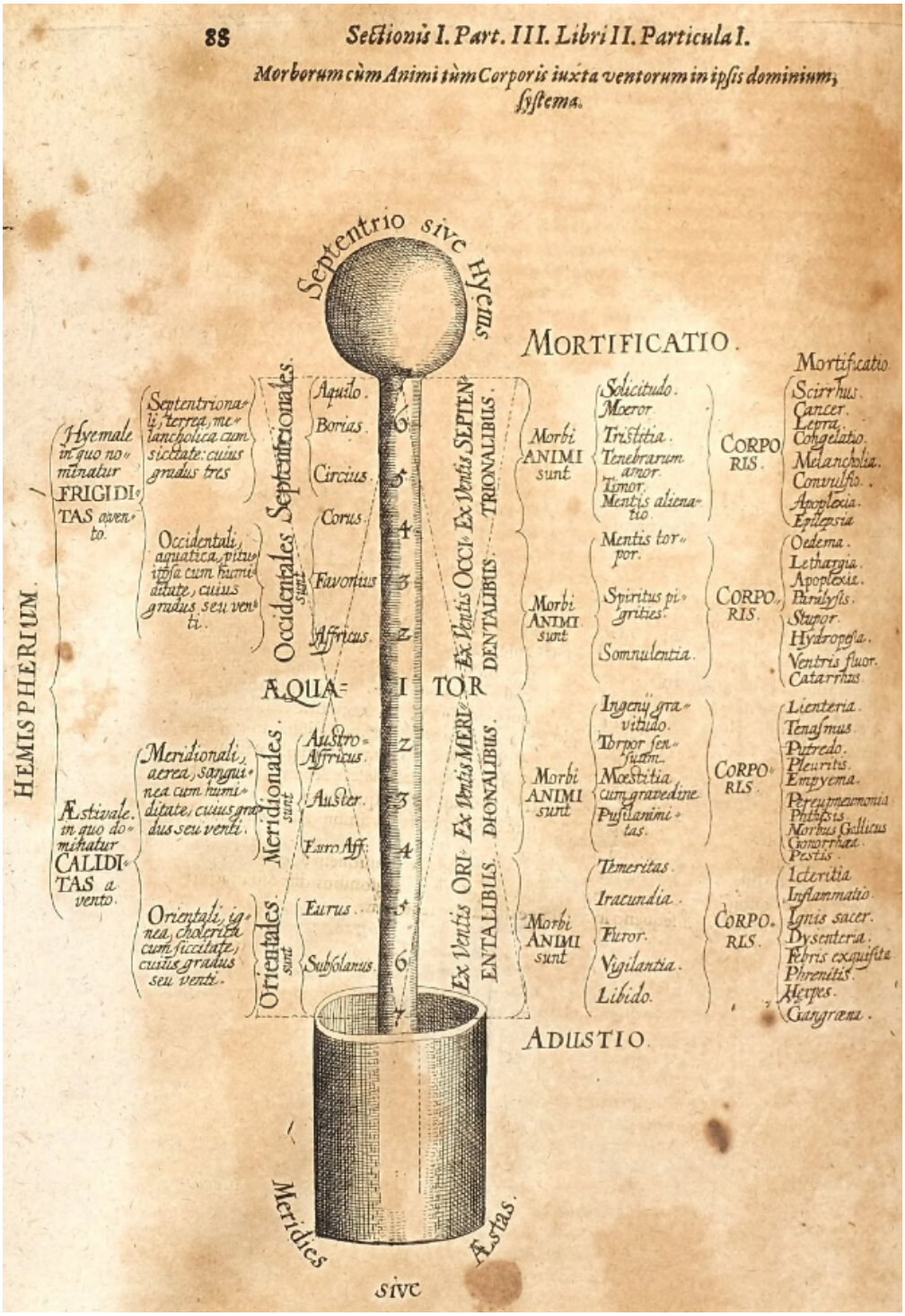

Figure 5: Fludd: Everything is connected. (Fludd 1631: 88)

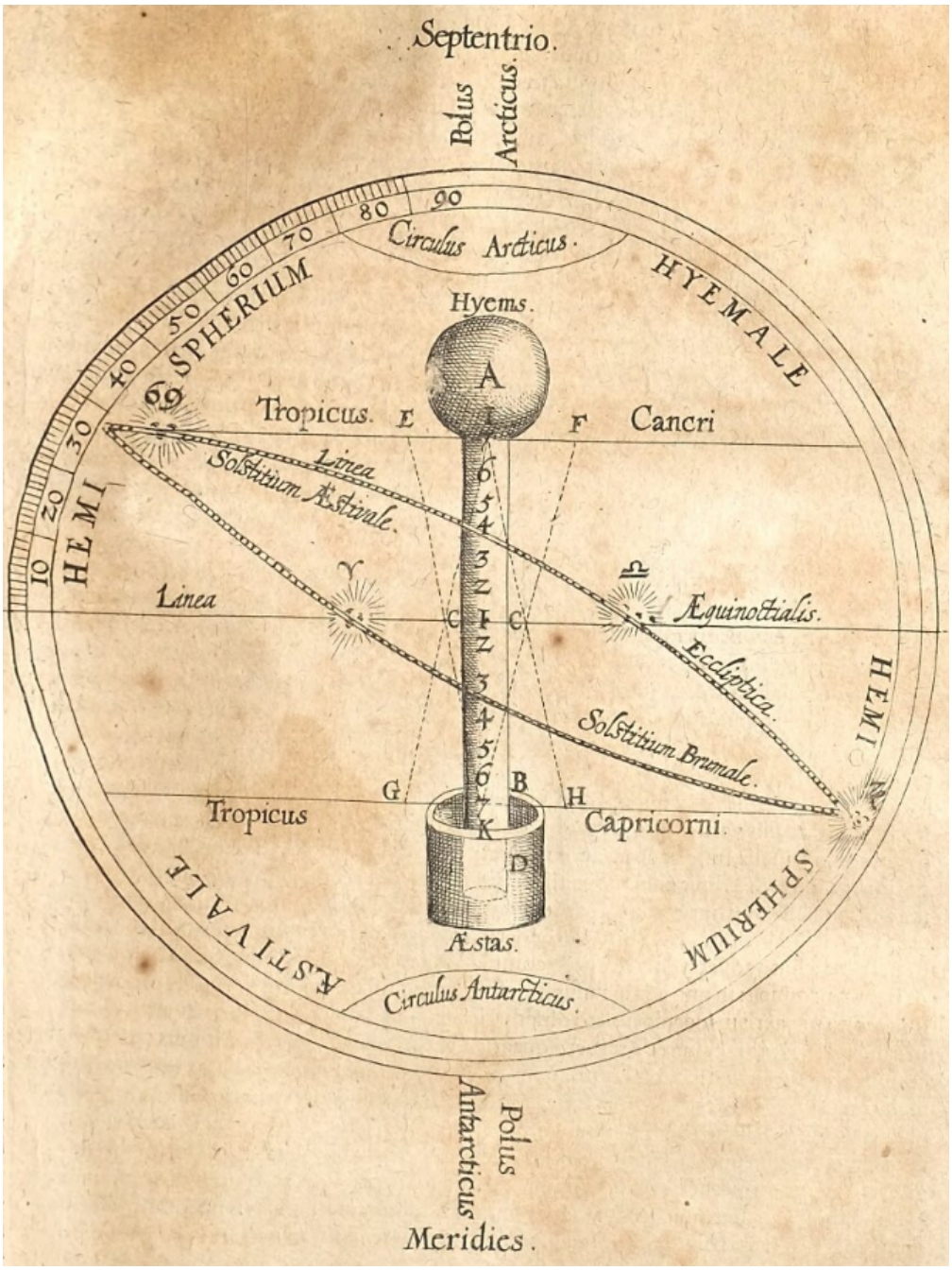

Figure 6: Robert Fludd: The barometer reveals the macrocosm (Fludd 1631: 51).

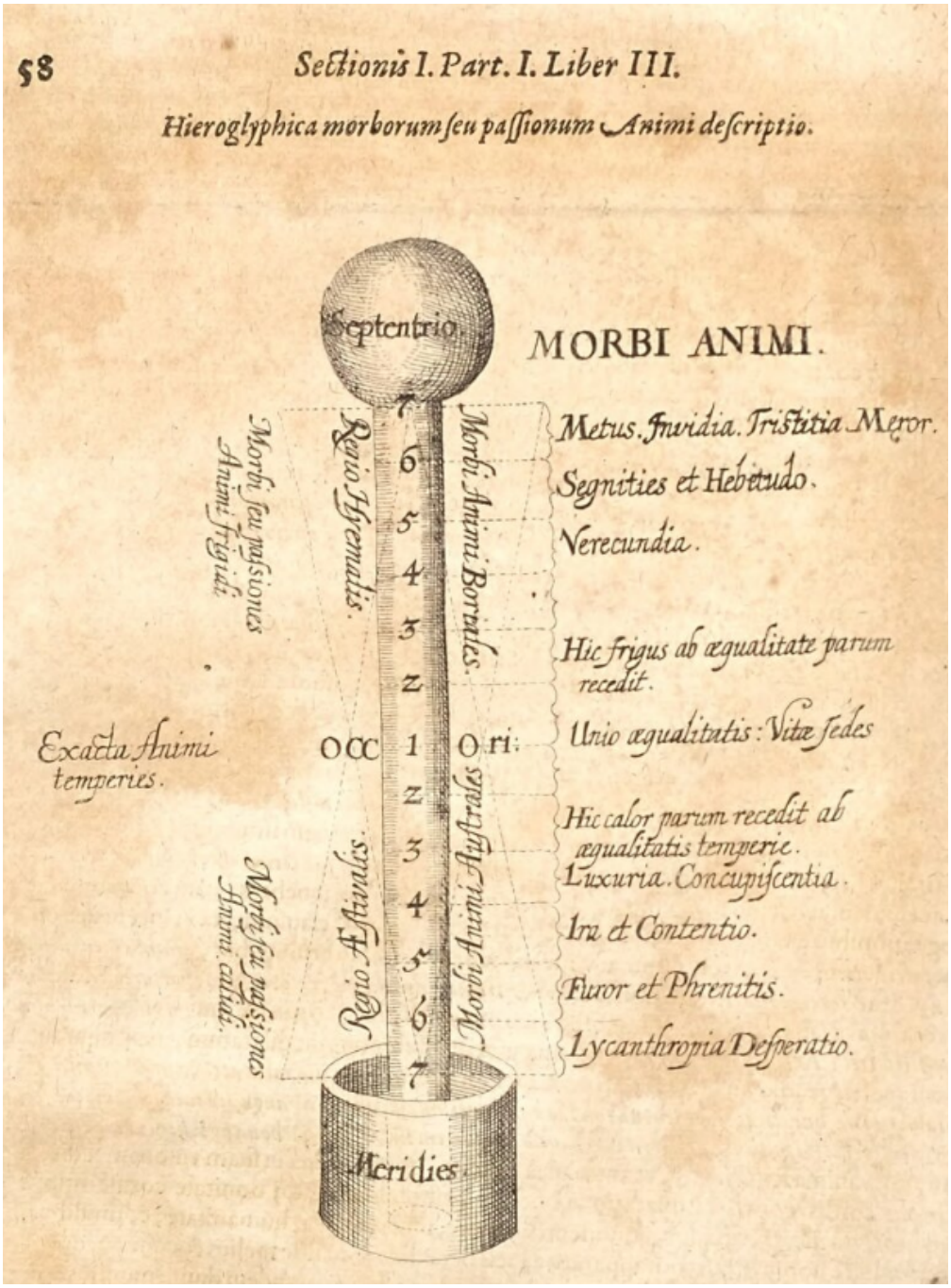

Figure 7: The barometer as an indicator for mental illnesses, ranging from *metus* (dread) and *tristitia* (melancholy)—both associated with the north (*septentrio*—down to "southern" conditions such as *furor et phrenitis* (rage and frenzy) and *lycanthropia desperatio* ("lycanthropic despair", an even more violent state of madness) (Fludd 1631: 58).

Figure 8: Fludd: The barometer as uroscope (Fludd 1631: 60)

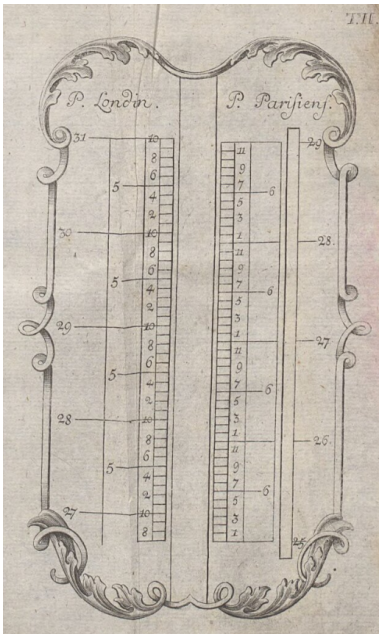

Figure 9: Hollmann 1783: Supplement, Tab. II

In the course of the 18th century instrument inventors and national learned societies introduced measuring systems of their own, resulting in multiple units and scales of measurement. Samuel Christian Hollmann provides in his guide *Nöthiger Unterricht von Barometern, und Thermometern* (1783) a conversion scheme for English and French barometric units and a synoptic table for different thermometer models (below).

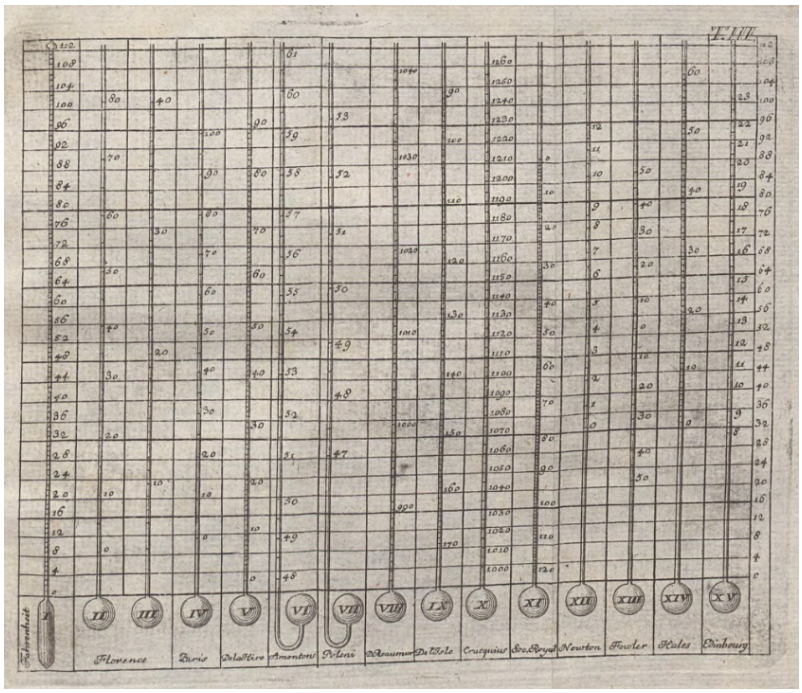

Figure 10: Hollmann 1783: Suppl., Tab. III

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