Johann Lambert's Scientific Tool Kit.

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With these four questions originate four sciences, that the human intellect has to use as just as many means and tools, if he wants, with conscience, recognize the truth as true, present it as true, and discern it from error and appearance. (Lambert 1764, I, X)1

Introduction: J.H. Lambert’s Tool Kit and Mode of Proceeding

In 1764 Johann Heinrich Lambert (1728-1777) published what is considered his main philosophical work, *Neues Organon* (Lambert 1764), followed in 1765 by the *Anlage zur Architectonic* (Lambert 1771a) that was published only in 1771. In these works, comprising near two-thousand pages, Lambert lays out his scientific views, discusses his way of proceeding in tackling scientific problems, presents heuristic methods and little tricks to overcome difficulties etc. Both books are the outcome of many years of scientific practice and of extensive reading. They contain the blueprint of Lambert's manner of conducting scientific work, both experimental and theoretical.2

For Lambert, the word *Organon* was to be quite literally understood in its original meaning, a tool kit (“Werkzeug”), a collection of tools to be employed, combined and assembled according to the problem at hand. As Lambert notices in some fragments of the logical and philosophical *Nachlass*:

> The routine (procedure) can be very different. Wolff liked to abstract. Baumgarten tried to apply abstract concepts to genera, to find new genera. Meier used his topic. Euler calculates. Dan. Bernoulli likes to use pictures as an aid. Muschenbroeck experiments without a theory. Others like to assume hypotheses. Everyone has his favourite guideline. (Lambert 1782 & 1787, I, 406–7)3

All these subroutines, partly taken from other scientists, partly self-developed, are discussed in Lambert’s *Neues Organon,* the *Architectonic* or one of his other writings. In particular, Lambert had written an *Organon* for ‘exact experimental physics’, an *Organon quantorum* which was included as the fourth part of the *Anlage zur Architectonic* “Die Größe” (Arch. §679– §923).4

In the last section of the *Neues Organon*, called *Dianoiologie* or the Doctrine of the Laws of Thought, Lambert gives a detailed account of his *modus procedendi* in things scientific (Lambert 1764, I, 386–450). In his obituary, a more succinct overview of the same procedure is described:

> He wrote down everything that came to his mind; he ordered these propositions after the common rules of logic; then he tried to find und fill up the gaps; then he consulted other books, especially dictionaries, to find the complete extension of a concept; and finally, he went through the whole thing with a logical table5 that he had published in the Nova Acta Eruditorum.6

Once this last stage is reached, Lambert wrote things up in a publishable form, partly inverting the order of invention into an order of exposition, viz. starting from a system of concepts, fine-tuning the concepts and linking them up in a series of experiments and a coherent body of propositions.

This near algorithmic scheme of invention and exposition is modulated according to the kind of investigations at hand.

However, Lambert was also aware that human knowledge is inherently incomplete and that many spheres of knowledge do not seem to be part of the same whole ([Lichtenberg] 1778, 277). Therefore Lambert conceived of an open-ended rather than a closed systematic approach, listing a variety of strategies and many exceptions to the rule. In particular in the near aphoristic fragments that were meant to supplement the *Neues Organon* but were only published after Lambert's death by Johann III Bernoulli, this aspect comes to the foreground. These fragments address parts of the art of finding ("Erfindungskunst"), mapping the ephemere geography of thinking, searching and finding. This is voiced in the conclusion to a long fragment on how to analytically transform experiments into a system, "the analytical method resembles a road to a hill, on top of which one can oversee the surroundings" (Lambert 1782 & 1787, II, 72).7 This road includes tracking down symptoms ("Kennzeichen"), following traces ("Spuren"), going side-roads ("Abwege"), doing detours ("Umwege") and having the lucky occasions ("glückliche Zufälle") and lucky ideas ("glückliche Einfälle"), finally, finding the right trick ("Kunstgriff") to handle things.8

Nearly all items in Lambert's scientific output, especially those that are part of an ongoing series of investigations over the years, testify of his systematic spirit and of his versatility in changing and adapting procedures to the circumstances. In the same way that the *Neues Organon* and the *Anlage zur Architectonic* refer to exemplary paragraphs from Lambert's earliest extensive investigations in experimental physics (the *Photometria* from 1760 and the *Tentamen de vi caloris* from 1755), his later investigations refer back to the relevant paragraphs in the *Organon* and *Architectonic.* This shows how practice informs Lambert's theoretical work and vice versa, how his practice is permeated by theoretical considerations. Nearly every series of continued investigations would thus serve to illustrate and explain Lambert's scientific approach, be it ballistics, the theory of comets, number theory etc. However, we have opted to discuss his hygrometric research because a wealth of documents is available for this case.

In 1769 Lambert devoted a long essay to the measurement of humidity and the construction, fine-tuning and 'synchronisation' of a measuring instrument, the hygrometer (Lambert 1769). In 1772 a second essay appeared that reported, processed and analyzed the results obtained by various persons with this experimental set-up (Lambert 1772). Complementing these richly detailed essays from Lambert's hand, there is an extant correspondance between Lambert, the instrument-maker Georg Friedrich Brander (1713–1783), and co-workers collecting the data from the hygrometers. As such, this case provides various insights into the process of setting up experiments, the material construction of the instrument, into making the experimental results communicable between experimentators and organising scientific data-gathering. Tying up these processes of doing science with Lambert's theoretical ideas, as expounded in the *Organon* and *Architectonic* will throw a new light on some of the philosophical and/or mathematical techniques and ideas Lambert is famous for (e.g. semiotics, statistics, visualizations...) and show their intimate embedding in a very general theory of (scientific) knowledge. This will bring out the unique character of Lambert's experimental work as an important and particularly enlightening link between the later 18th century, characterized by Newtonian experimentalism on the one hand and an (mostly independent) exploration of mathematical techniques on the other hand, and the 19th century, marked by the combination of a strict mathematical approach with organized laboratory experiments.

The context of Lambert's work on hygrometry

Looking at the publications on the measurement of air humidity during the 18th century, it is immediately apparent that between the years 1760 and 1790 the topic was a popular one. At both sides of the Canal many essays and books appeared discussing the construction of a hygrometer and the design of a scale for measuring humidity.9 The study of humidity was part of a more general interest in all things pertaining to the weather. In the 18th century, meteorology, the study of the weather, held an appeal for many researchers, because it had connections with many other sciences (physics, chemistry, electricity, ...), and seemed particularly amenable to quantificative observations and measurements, preparing the ground for laws that could be mathematically expressed.10 In particular, metereologists were among the first in designing precise instruments for experimental physics (Feldman 1990, 145). Lambert's work on hygrometry is deeply embedded in this context and subscribes to many characteristics of a late 18th century physics which Feldman has baptized 'exact experimental physics'.11 Lambert's main source and influence in hygrometry was Petrus Musschenbroek, under whom he had studied in Leiden (1757–58). Thanks to Lambert's and de Saussure's work in the 1770ies and 1780ies Dalton's law of partial pressures would eventually be formulated for the special case of aqueous vapor in 1801.

Coming to questions

Asking the right questions when setting up and performing experiments is not a trivial task. Lambert had written in the preface to his *Neues Organon* (Lambert 1764, I, VII) that a theory of questions is as important as a theory of propositions (see also Dian. §423–550). Upon his becoming member of the Berlin Academy, Class of Experimental Physics, Lambert described the problem in the following words:

> Purposeful experiments in chosen circumstances are problems that we propose to Nature. [...] She responds with precision, not to what we think we ask, but to what we actually ask. To avoid being deluded and waiting for nothing, one has to rigorously make sure that the conditions imposed by the problem are known, so that one is able to chose the circumstances and to adapt the experiment to these conditions. (Lambert 1765/1767a, 508)12

The question of what constitutes a 'good' experimental question is for Lambert intimately related to mechanism and mathematics.

> Experimental physics is absolutely necessary in cases where there is no way to see the mechanism by which Nature operates [...] one can add calculation, one can apply the principles of mechanics where this mechanism is pronounced enough to be seen or simple enough to be conceived of. (Lambert, 1765/1767a, 509)13

The translation of the observed 'mechanism' into mathematical language ties experimental physics up with mathematics, both being indispensible for the development of the other and functioning as check mechanisms, one for the other:

> Calculation brings in precision and generality. Experiment (Experience) verifies both and discovers each circumstance omitted or falsely admitted. Neglecting calculation and the theory one performs arbitrary and aimless experiments. Neglecting experiments one is in danger of running into chimeras and of producing calculations that apply in every other world but this one. (Lambert, 1765/1767a, 509)14

Lambert's use of the word 'mechanism' might seem curious, but it should be interpreted neither as an avowal of a pure mechanical world view, nor as a shallow metaphor. It is rooted in the observation that all machines have periodic behaviour (Arch. §332). On other occasions, Lambert also uses the word 'rules' ("Regeln") to indicate this same relationship between observable behaviour and underlying regularities.

To find the requirements under which something (e.g. a machine) has a certain effect (e.g. behaviour) is to Lambert an instance of a very general logico-philosophical problem, viz. that of reversing propositions, i.e. turning a proposition of the form Subject/Predicate into a proposition of the form Predicate/Subject (Lambert 1782 & 1787, I, 499). Following Wolff, Lambert saw in revertible propositions ("Umkehrsätze") the most powerful and richest propositions of science because it makes the concept (the subject of the proposition) completely clear and understood (Dian. § 676). Therefore, "all coordinate scientific ideas are connected through reverse propositions" (Lambert 1782 & 1787, I, 496).15 Its analytical form could be seen as Lambert's basic scientific research principle (Sem. § 94):

> If a thing is given that is made after certain rules, to find the rules after which it was

made or could have been made.16

It should, however, be remarked that in Lambert's view phenomena that obey 'rules' or 'mechanisms' are only one class of natural phenomena. Another class contain those that are generated by laws ("gesetzmässig"), yet another class those that are or appear random ("zufällig"). As this last category makes very clear, Lambert's classes are phenomenological categories, indicating the knowledge of the investigating subject about the object of investigation. Lambert largely expounds upon these categories in his *Architectonic* (Arch. §307–350). They are mainly heuristic categories, i.e., given a set of (quantitative) data obtained during a stretch of time, how can find the rule or law that gouverns the order or non-order of this data set? If the set appears random, it can be a series of random events, or a series generated by a law. If, however, the set is ordered, i.e., there are similarities or repetitions between adjacent data, the set can be generated by a rule, by a mechanism. Lambert calls this last class of local order and considers it to be the most tractable set of problems in Nature, as expressed in the quote above.17

A sure sign of such local order is periodicity (Arch. §327). Hence, to start an investigation into the laws of Nature, to start a new discipline, one can focus on periodic phenomena first, try to derive their rules and then gradually expand the theory. This is exactly Lambert's purpose in meteorology:

> It seems to me that if one wants to make meteorology more scientific than it currently is, one should imitate the astronomers who began with establishing general laws and middle movements without bothering too much with details first. [...] Should one not do the same in meteorology? It is a sure fact that meteorology has general laws and that it contains a great number of periodic phenomena. But we can but scarcely guess these latter. Only few observations have been made so far, and between these one cannot find connections. (Lambert 1771b, 60) 18

To obtain more and better data Lambert proposed to set up a network of weather stations around the world, in which the various weather configurations (rain, clouds, dry ...) would be recorded with the use of a simple and small set of iconic signs, the ones still used nowadays in the weather report.19 Furthermore, he promised to devote himself to the improvement of the measuring instruments and to the developement of accurate concepts and a theory for the advancement of meteorology. This is delivered in the 1769 and 1771 texts on hygrometry.

An epistemological observation on Lambert's concept of periodicity is due. Lambert's periodicity seems to be an intermediate concept, turning phenomena and/or patterns present in the data slowly into laws, turning the similarities into quantitative series, in which structures and dependencies can be tracked down (as his three categories of order indicate rather explicitly).20 Similarly, Lambert's transformation of a classical device of structuring scientific knowledge, the logical proposition and its reversal, into an analytical principle that bears resemblance to the modern black-box analysis, also seem to be a symptom of a much more general shift in knowledge structuration. This matches up with Foucault's analysis in *Les mots et les choses*, where, for the period around 1800, a discontinuity in the representation of knowledge is described, going from classification and an ordering device based on similarities towards structures and derivational order (Foucault 1966).

What is humidity?

The main question to be solved in Lambert's introduction to the 1769-paper is to determine what humidity really is, what other phenomena act upon on it, and how these can be put into a quantitative form. As put forward in the *modus procedendi,* Lambert starts by considering the word 'humidity' in all its significations and figures of speech, as they can be found in a dictionary. "to find the complete extension of a concept". This way, Lambert connects to the common understanding of a phenomenon, as it appears in everyday conversation, and can, starting from there, gradually specify the phenomenon as appearing in his scientific research.

> It is not necessary to explain what humidity is. On has only to pass through the fog to perceive it; because this is a kind of humidity immediately accessible to eyeview and sense of touch. One can also see it in the exhalations of boiling fluids. It also becomes

visible in the Winter, when it attaches itself to windows or covers objects exposed to vaporous air, or, finally, when it appears as dew that covers the hairy surface of plants with an infinity of small drops. If in the Winter one transports the cold into heated rooms it attaches itself to glass or metallic bodies. This is known to everybody. (Lambert 1769, 69)21

Especially the phenomena where humidity can be seen or felt are emphasized, as a way of linking up non-scientific, everyday experience with controlled scientific experimenting.

Lambert conceived of language as an 'archive of concepts' ("Behältnis der Begriffe"), ready to be used and developed. The goal of semiotics is to "reduce the theory of things to the theory of signs" (Sem. §23-24), or put differently, to adjust and control the mapping between the elements of the real world ("Realwelt") and the intellectual world ("Intellektualwelt"). Because everyday language has much that is 'hypothetical' or 'arbitrary' ("hypothetisch"; "willkührlich") – one could say in modern terms, language has much redundancy (on the semantic level) – one needs procedures to adjust this mapping when words are needed for specific, scientific discourses (Sem., §329-351).22 For Lambert, a scientific discourse is more amenable to quantification than everyday speech and specifically should be 'designed' to avoid endless discussion and polemic ("Wortstreit", "logomachia"). Therefore, scientific concepts ("Begriffe") should be developed so that they are clear, understandable, but also fit for further refinement, either narrowing down its extension or broadening it ("den Begriffsumfang bestimmen"). This way, Lambert hoped to avoid the endless definitions and repudiations of the Scholastics or of the Wolffian *Schulphilosophie* that hindered the progress of science. Lambert discerned two modes in which the process of determining the extension of a concept could proceed: oscillatory or asymptotic (Arch. §561). The first mode is a series of consecutive definitions where the next definition contradicts the previous one, the second mode of defining is the one Lambert wanted to establish in science, the determination of a concept with ever increasing precision and consensus.23 Such determination and/or adjustment is possible through the use of 'coefficients', i.e., the adjectives and adverbs that determine the substantives and verbs (that act like variables) (Arch. §437, cfr. Sem. § 176, 223).

> These [concepts and qualities] are not simply put or thrown together, but are multiplied [with the coefficients, adjectives and adverbs], because the abstract concept acquires new qualities.24

Proceeding this way, from everyday words to gradually determined words, one can avoid to invent artificial words.25 Using the resources present in everyday language, understandability between scientists and non-scientists (or for that reason, between different branches of science) is guaranteed, and, perfectibility of the concept is inherent to the definition of the concept, it can be adapted to the outcomes of the experiments and theory, the use of common everyday devices present in language (determination through adjectives and adverbs) are the guarantees for that.

This is exactly what Lambert does after introducing the concept 'humidity' with the dictionary examples, it is determined further for scientific use:

> The degree of humidity of air is the mass or better even the weight of all aqueous particles that float in a certain volume (e.g. in a cubic foot of air). *This is what the language of hygrometers should be reduced to*. (Lambert 1769, 69, my italics)26

Everything ambiguous that was possibly present in the word 'humidity' is thus equated with a definition that allows quantitative determination. This reduces the linguistic application range of humidity, but makes it amenable to the scientific language which is mathematics. Mathematics, or to be more exact: algebra, is for Lambert the characteristic language per se that can be bsponest perfected so as to induce a proper mapping of the real into the intellectual world (Sem. §35).

Again, Lambert tries to get at the exact extension of the concept humidity by "reverse engineering", viz. making the concept not a subject but a predicate, determining the requirements for humidity to happen (Dian. § 676).

> Let us try to track [humidity] in its majors appearances that can be evaluated and

measured. Les us begin to see it at the time of its birth. (Lambert 1769, 69)27

This leads to the investigation of evaporation, because evaporation causes the change of humidity. If one can “evaluate and measure” evaporation, one will know humidity since it is gouverned by evaporation.

Evaporation: Experiments and Graphs

Evaporation had been experimentally researched by the Dutch professor Petrus Musschenbroek in the course of his research on capillary forces (Pater 1979, 227–290). He had derived a correlation between the amount of evaporation and the total mass of water (not only the surface), these being in inverse proportion. Lambert’s first scientific publication in the *Acta Helvetica* (1755) repeated Musschenbroek’s experiments, because it was not clear whether Musschenbroek had taken into account all circumstances that entered into the problem and whether Musschenbroek had described the circumstances of the experiments with due detail (Lambert 1769, 70). Lambert’s results did not completely agree with Musschenbroek’s conclusions, but it was only some years later, Lambert having differed to settle the matter, that the Swede Wallerius “with much care” did similar experiments but came to the conclusion that evaporation correlates with the surface of the water only, and with the temperature and wind. Lambert concludes: “the cause of evaporation [lies] in the contiguity of air and water” (Lambert 1769, 72).

To settle if either Musschenbroek’s hypothesis or Wallerius’s was right, Lambert repeated the experiment in his own chamber (in three different set-ups), detailing the conditions of the experiment, even noting if he left his window open or not (which Lambert did in August, because it was too hot). His results confirmed Wallerius (Lambert 1769, 76 and 85).

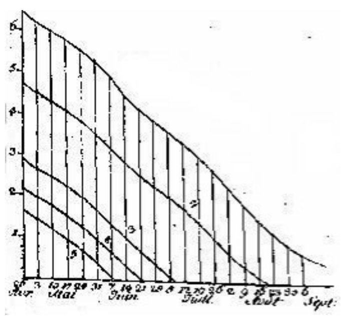


Figure 1: Lambert's visualization of the evaporation experiments, each line corresponds to a vessel.

Lambert does not only detail his experiments and carefully enter all conditions and measurements in his table of data, but adds another means of data representation. Lambert visualizes his data, a strategy quite unusual in its time but of which Lambert is a forerunner.28 As Lambert notes, “I will not make long comparisons with the numbers in this table, because one can see it *d’un seul coup d’oeuil* when the numbers change into figures.” (Lambert 1769, 76) Representing the data in five seperate graphs (corresponding to the five different vessels) with the height of the water on the Y-axis, the passing of time on the X-axis, it becomes immediately clear that the all five graphs are more or less parallel to each other, and thus, that the relationship between water height and time is a simple linear one (Figure 1).

Lambert’s use of visual strategies is connected to his views on the ‘appearance’ (“Schein”) of things, as explained in his Phänomenologie. Perspective or spheric geometry used in astronomy are examples of a ‘language of appearances’ (“Sprache des Scheins”) that can be helpful to simplify certain problems as long as it can be retranslated into the language of reality (Phän. §5). Although visualizations belong to the ‘language of appearances’, they can be useful to determine the truth. In a discussion on figure and symbol (“Figur” and “Zeichen”) in the Semiotik (§52–64), Lambert explains that the figure can represent a specific case, a concrete thing, whereas its translation into algebraic signs makes it more general, abstracts from particulars (Sem. §57–8 and 62).29 Translation into algebraic signs makes it possible not only to find one solution, one particularization, but to find – by syntactically linking up the signs – all solutions, all cases (Sem. §63–66).

However, when doing experimental physics, Lambert details the relationship between *Figur* and *Zeichen*. He does this in the fourth part of the *Anlage zur Architectonic*, the 30th chapter, “Die Schranken”, the limits. Here, he discusses the limits of precision within algebra (e.g. errors produced by rounding off, non-convergent series) and within the measuring and recording of phenomena. The precision of measuring instruments, the number of observations etc. all introduce limits to the precision of the obtained results. Therefore, in many cases, a (mechanical or geometrical) construction or a figure may be as precise or as suitable as a calculation for obtaining results, as long as the precision of the data is less than the precision of the construction or figure (Arch. §864-865).

Hygrometry being a young science with but few undebatable results and even fewer standards, visualizations can be of great value. For instance, Lambert sets up some experiments to determine the relationship between air, water, heat and evaporation and concludes, on the basis of graphs of the experimental results, that air causes the evaporation and that heat (forcing the particles to dilatate) contributes greatly to the celerity of the evaporation. On the basis of first graph (the upper one in our Figure 2) it jumps to the eye that heat and evaporation are correlated. On the basis of a mechanical differentation Lambert obtains the lower figure in our Figure 2. He remarks

> It would be quite difficult to give a priori an algebraic equation that satisfies the curve of [this] figure. [...] but we can always indicate the general symptoms that the curve has to satisfy. (Lambert 1769, 87)30

The curve, containing points with a temperature and a water height component, indicates that the celerity of evaporation depends exponentially on the increase of heat. Lambert also notes that the curve implies that evaporation also happens, though slowly, beyond freezing point, and becomes very fast beyond boiling point, though for neither phenomenon does he venture to decide if these are asymptotic axes of the curve. In other words, Lambert is doubtful whether there is an absolute point of temperature where the evaporation begins or stops.

For practical reasons Lambert determines a parabole-like curve that locally fits the curve of the lower figure (in our Figure 2) between zero and 60 degrees (Réaumur, corresponds to 0 to 75 degrees Celsius). He simply fits the equation to all experimental points of the curve according to the method set out in (Arch. §894 and 899). The equation is:

$$y= 2/10\, x + 1/200\, x^2 + 13/72000\, x^3 + ...$$

Lambert is perhaps the major forerunner of modern statistical techniques, both graphically and computationally,31 These graphs and their interpretation and manipulations function as a sort of midwivery for mathematical formulae that would connect the observational data. It need thus not wonder if Lambert experiments a little with this equation. Getting rid of the zeros in the fractional part, he arrives at the equation

$$4/3\, x + 1/3\, x^2 + 13/72\, x^3 + ...$$

and remarks that this comes close to

$$x + ½\, x^2 + 1/6\, x^3 + ...$$

which is the power expansion of e^x-1. Ultimately he derives a hypothetical differential equation *dy=mydz* that gouverns the growth of evaporation (Lambert 1769, 90), though only for the ‘regular’ interval given above. Also, the air pressure and the humidity of the air are not taken into account.32

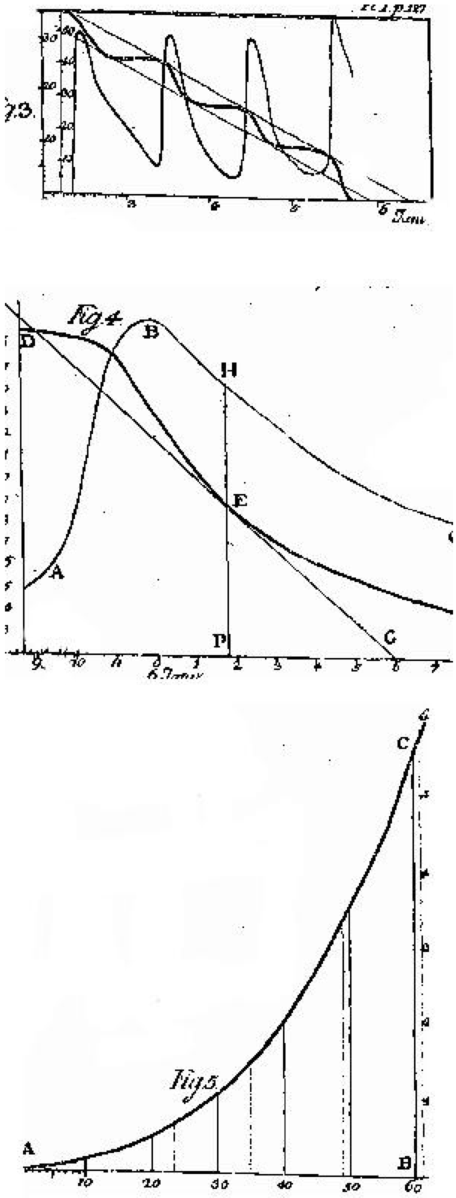


Figure 2: Transformation of Graphs in Lambert's Hygrometric Studies: The upper figure represents the temperature (the oscillating curve) and the loss of humidity (the steadily decreasing curve), their correlation is made evident by the intelligent design of the graph showing the meeting points of both curves; the middle figure is a blown-up detail of the upper figure with a tangent on the humidity curve; the lower figure is obtained by graphically displaying the intersection points of the tangents on the humidity curve with the X-axis, i.e. the mechanical differentation of the humidity curve which generates a curve of the rate of evaporation.

Setting up the Hygrometer

Asking questions to Nature is much like an experiment in trying to understand and speak its language.

> Barometers spoke an intelligible language from the day they were invented; the thermometer did not speak so clearly at first. Only in 1714 did Fahrenheit give to Wolff two corresponding thermometers, and even today this language is only a comparative one. [...] We have to take a closer look at the hygrometers to try and understand their

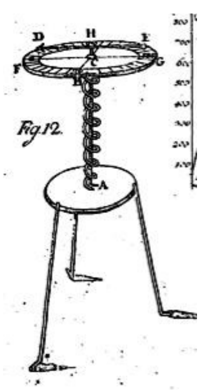
languages and to make it intelligible. (Lambert 1769, 68)33

Indeed, though the boiling point of water served as the fixed point for the common sense use of thermometers end of the 18th century, its further scientific determination would be the matter of much research and debate inasmuch that the Royal Society assembled a committee to make recommendations about a standard fixed point (Chang 2004, 8-17). Moreover, the comparability of thermometers (i.e. the correspondence of their scales) would remain problematic until the middle of the 19th century (Chang 2004, 57-102).

In a long discussion on measure and scale ("Maaßstab", Arch. § 759-783) Lambert discerns between three kinds of relationship between a quantity and its measure. First, the case where the unit of measurement and the thing to be measured are of the same nature, its quality and dimension known and thus comparable to other quantities (e.g. length in geometry, height in barometry, Arch. § 761-762). Second, where the unit of measurement and the thing to be measured are of the same nature but defy comparison with other quantities (e.g. weight, Arch. § 763). Last, the case where not the quantity itself, but only an effect or a connected quantity can be measured, a case that gets worse when only "greater than" or "lesser than" can be measured (Arch. § 764). Here are thermometry and hygrometry to be situated.

Although Lambert does not make this explicit, his own "measure" of the three classes is forged after a distinction between different kinds of physical appearances. Either the appearance (e.g. the representation of a phenomenon) differs only gradually from its true nature (e.g. a drawing for a solid body, a line for a movement), or it they are of a different nature ("nach der Art verschieden"), as e.g. our representation of colour and tone is not in the same medium as colour and tone themselves (Phän. § 85, § 92-93). As a consequence the mapping between things and their concepts/signs is more difficult in the second case. Lambert's two classes of appearance, or three classes of measurement thus reflect a degree of comparability/communicatibility.

Here, the thermometer is better off because they can be made corresponding (the same degree of heat can be measured under specified circumstances), though an absolute degree of heat is still missing. The hygrometer then is only "a very imperfect display of humidity" (Arch. § 764). Lambert also remarks (Arch. § 779) that there are often limits to the measurement, giving the example of a thermometer that might approximately behave linearly during a certain interval, but rather more complex at the extremities (boiling and freezing). In that case, Lambert advises to draw a graph and analyse its symptoms, so as to study the simple quantity and its complexifications piecewise ("stückweise"). This is exactly what Lambert sets out to do for the hygrometer using the "tame" part of his curve of evaporation between zero and 60 degrees Réaumur.



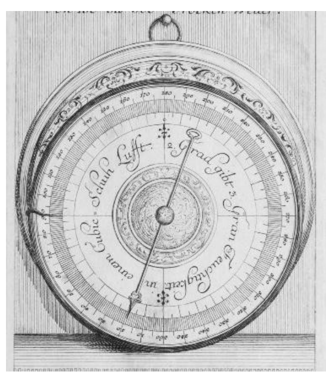


Figure 3: Left, Lambert's original set-up of the hygrometer; right, the ulterior design of the Lambert-Brander hygrometer

In the perfection of the hygrometer, the first problem to settle is what substance should be used to measure humidity? Lambert lists the then viable options: Wood, cords, sponges – and chooses the thin cords, with which he had already 15 years of experience (Lambert, 1769, 92). Figure 3 shows his set-up of the hygrometer, a cord wound around a metal stick, with a 'dial' on top of it to measure the rotation of the threads in the cords. Given this, "I still had to submit my hygrometers to other tests so as to get to know their language and the law of their variations" (Lambert 1769, 101)34 This comes down to 'synchronizing' the behaviour of the hygrometers with the extremes of the curve of evaporation, to find their points of "absolute" dryness and wetness.

Enclosing the hygrometers in a bottle and turning the heat on, Lambert finds that from a certain temperature onwards the drying up slows considerably down. Repeating this experience over several days, the hygrometer comes to a stand. Displaying his data in a graph, Lambert concludes: "it seems there is something asymptotical there" (Lambert, 1769, 107). Similarly, Lambert tries different procedures to find the maximum of humidity for his hygrometer, and finally comes up with a graph of data where a certain "concavity" in the graph shows up (Lambert 1769, 119–120). As a final check on his experiments in fine-tuning the hygrometer, to compare the rate of evaporation directly with the movement of the hygrometer's dial, Lambert puts both their parallel evolutions in graphs (Figure 4). The general symptoms of both curves indeed concord, but it is clear that the hygrometer only absorbs (and hence displays) a certain percentage of the humidity present in the air.35

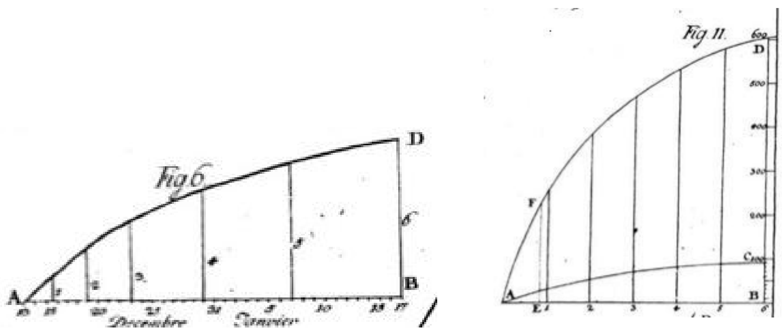


Figure 4: The graphs that show the match between the curve of evaporation (left) and the curve of the hygrometer (right)

The 1769-article ends with an interesting side-track ("Abweg"), an essay in finding a mathematical way to quantify the evaporation in sponges (Lambert 1769, 123-126). Lamberts sets up an expirement with three sponges of increasing size. Although some parallelism between the curves of evaporation from the three sponges is visible, Lambert remarks that the relationship between the surface of the sponge and its volume makes them difficult to handle, since evaporation on the surface must take away the mass of water in the sponge's volume. Having no procedure at hand to calculate the surface of a sponge (fractal geometry still 200 years away),36 Lambert concludes sponges are indeed not suited for building a steady quantitative instrument.37

Correspondences

It had been Lambert's ambition in his 1769-article, not only to perfect the hygrometer, to find its quantitative language, but also to find an absolute quantitative language, absolute measurement. His experiments had, however, shown the difficulty (if not impossibility with the instruments of his time) to determine an absolute degree of dryness or wetness. Instead of this, Lambert had been able to define a comparative language with two marker points (not unlike the thermometer but with a much more irregular behaviour in between). These marker points (a 'gentle' minimum and maximum of humidity) were defined by their procedures. Lambert had indicated the dimensions of the tubes used, the quantity of water, heat involved etc. to assure that (Lambert 1769, 107 and 119). This way, assuming hygrometers of the same materials and quality, hygrometers could be made "corresponding" between observers and experiments.

Immediately after the publication of the first paper on hygrometry, Lambert sent a copy of the paper to his long-time friend, the instrument maker Georg Friedrich Brander in Augsburg.38 In the accompanying letter of November 1771, Lambert instigates Brander to start manufacturing corresponding hygrometers (Lambert 1781-1787, IV, 308). “I would like to see this hygrometer become a common instrument, and then the essay itself can be translated.”39 A dialoge between Lambert and Brander running over more than three years ensues over how to make the hygrometers corresponding.

It becomes rather quickly clear that Lambert’s procedures in his 1769-essay to fix the marker points do not function very well. Although the degree of average humidity (“Grad der mittleren Feuchtigkeit”) functions rather well as a point of correspondence between two hygrometers, the extremes do not. Other procedures to fix the extreme marker points are discussed and Brander comes with the idea to use the average degree as a fix point together with a scale to ‘synchronize’ hygrometers per degree.40 In the end, the two correspondents agree to make a standard hygrometer (“Normalhygrometer”) to ‘synchronize’ the hygrometers (Lambert 1781-1787, IV, 351–352 and 357–358). A tentative correspondence between Lambert’s and Brander’s hygrometers is finally achieved end of December 1772.41

By this time, Lambert had not only his own hygrometric observations, but also those of the prelate Felbiger in Sagan42 , those of Maschenbäuer’s, a friend of Brander in Augsburg, and finally those of Professor Titius in Wittenberg, who had, independently of Lambert, started to make a hygrometer. According to the *Monatsbuch*, Lambert’s scientific diary, Lambert devoted April to June of 1772 to comparing and collating the observations (Bopp 1916, 31). The result of it all is put into one large graph, displaying the observations of each participant (Figure 5). The correspondence with Brander and the graph are the immediate materials that went in Lambert’s 1772-article, ‘Suite de l’essai d’hygrometrie’ (Lambert 1772).

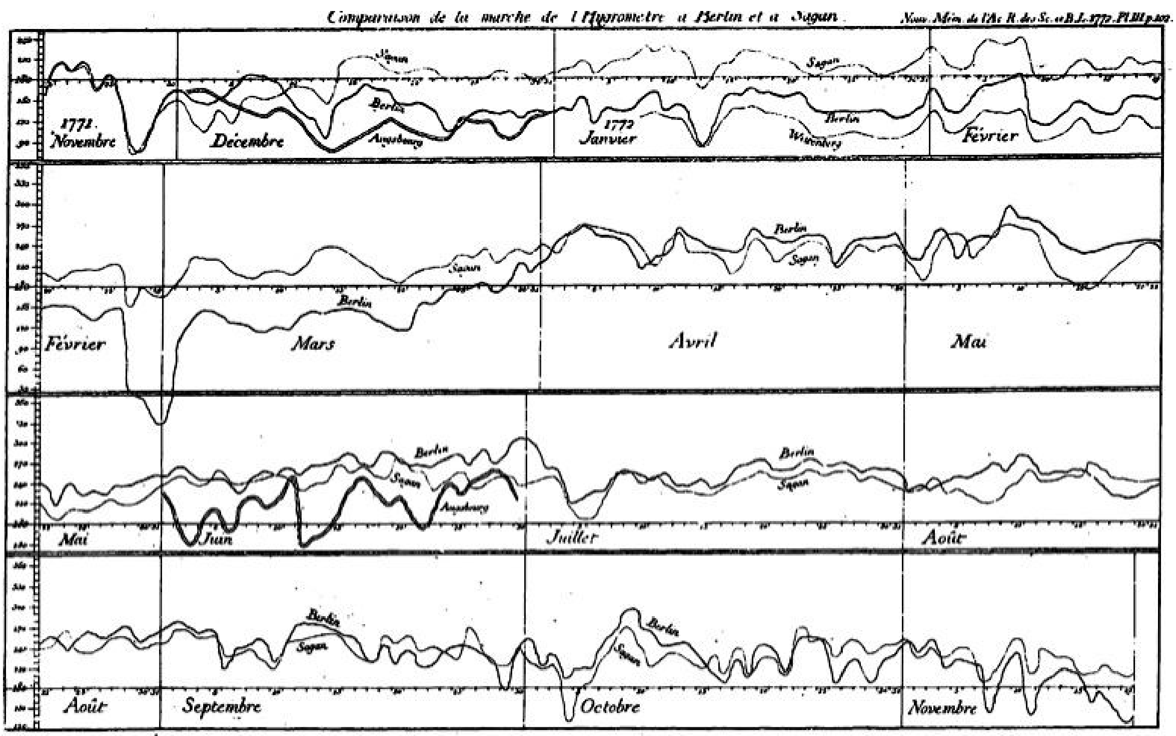


Figure 5: Lambert's master graph, collating all hygrometer observations and the basis of his (a priori) derivation of a meteorological law

The graph shows that the observations of all participants are in accordance, at least if one only looks at the contours and the relative maxima and minima. Although Lambert admits that the material is scarcely enough to find annual regularities or other periodicities, he endeavors to search for an equation fitting the observations. He starts with a hypothetical formula, relating humidity to the longitude of the sun (i.e., to the expected temperature of the season):

$$y=A+B \sin x +C \cos x +D \sin 2x +E \cos 2x...$$

In a first approximation, the formula becomes $y=B \sin x$, which fits the curve reasonably well, abstracting from the actual shape of the observations curve, and looking only at the cutting points with a middle axis of intermediate humidity, which is the arithmetical middle of the observations (Lambert 1772, 75–76).

To check his tentative formula, Lambert compares it with the measurements (on a sponge hygrometer) that Crucquius published in the *Transactions of the Royal Society* from 1721 to 1723. Lambert sees his hypothesis confirmed: the increase and decrease of humidity varies more or less like the increase and decrease of temperature, with a phase shift of 4 to 5 weeks (Lambert 1772, 76–79). At long last, Lambert is able to execute part of his program on meteorology, to find periodicities and quantify them.

Discussion

In his hygrometric studies Lambert attests his skills both as a very conscientious experimenter, operating on a similar level as his contemporaries H.B. de Saussure (1740-1799) or J.-A. De Luc (1727-1817), and as a resourceful applied mathematician, in this respect the equal of L. Euler (1707-1783) and close in spirit to Tobias Mayer (1723-1762). What makes Lambert quite a unique apparition in the latter half of the 18th century is not this combination of experimental and mathematical practice as such, but the fact it is inherently and consistently embedded in a rich systematic philosophy of knowledge and theory of science. As our "dissection" of Lambert's hygrometry shows, the four parts of the *Neues Organon* provide the main lines of direction (how to sharpen a concept, how to deal with the appearance of things, what kind of propositions to look for...), but it is mainly the substantiation of these general guidelines for the case of applied mathematics/experimental science in the fourth part of the *Anlage zur Architectonic* (*Organon Quantorum*) that directly pours into Lambert's practice.

In particular in the cases where the gap between the thing to be studied and its scientific apprehension (be it as a concept, a measurement or a theory) is large, Lambert's strategies and heuristics laid down in the *Organon Quantorum* are quite performant. The semantic determination of the concept humidity (cfr. Arch. § 437, 561**),** the graph of evaporation and its subsequent manipulations until the derivation of a differential equation (cfr. Arch. §885–902), or the tuning of the hygrometer using extremes of the "tame" behaviour of evaporation (cfr. Arch. § 779) are neat examples of how Lambert finds his way out of an impasse. Where experimental research is at its end, Lambert throws in mathematical and mathematico-mechanical (e.g. mechanical differentiation, graphs) techniques.43 This way, the "grey zone" between a thing and its apprehension can be explored or even mapped, be it piecewise.

As the usage of the graphs in the hygrometric studies shows, this exploring/mapping of a "grey zone" may be a posteriori (e.g., the graph of evaporation yields an equation), but it may also be directed by an a priori determination of the expected result (either because extra knowledge is added or because an assumption is made), as is the case for the derivation of humidity equation. It must be added that Lambert's tricks did not always lead to correct or the best results, mainly because Lambert trusted mathematics and theoretical considerations too much. For the synchronization of the hygrometer it turned out that Brander's method of a scale around "average humidity" functioned better than Lambert's fitting to the graph's extremes. And in the case of a study on magnetism Lambert derived an erroneous equation because an a priori assumption made him "misread" his graph (Gray and Tilling 1978, 26).

However, more often than not, the embedding of his scientific practice into a open but systematic theory with an eye for heuristics, inherent limitations and problems, gave Lambert a firm methodological advantage over his contemporaries as for instance Jean-André De Luc, who may be regarded as a typical exponent of late 18th century experimental physics. As recent scholarship has stressed, De Luc's investigations are characterized by a worry to "stabilize" the object of the experiments, on the level of description and prescription as well as on the level of measurement.44 It resulted in a meticulous description of the experiment, its set-up, conditions and results and a nearly unsurveyable heap of data and detail collected during the many variations of the experiments. Although De Luc studied boiling with 8 kinds of thermometers and varied the conditions of the experiments, all duly described, he ended up with a list-like phenomenology of what boiling was or could be (Chang 2004, 20 and 60-64). An injection of Lambert's methodology might have done wonders here: For semantically narrowing down the concept of boiling in advance; for plotting the many data to obtain characteristic symptoms and reduce the sheer amount of information gathered in the experiments; and finally, for applying some probabilistic logic (as laid out in Phän. § 149-262) to the list-like results of the experiments.45

In this comparison of De Luc and Lambert, one may indeed recognize an "epistemic shift" (Hofmann 2006, 49-50; 52-53). On the one hand, De Luc can be regarded as an example of the 18th century experimenter's philosophy where the measurement and the instrument may be perfected without limits if only detailed description and prescription are followed. On the other hand, Lambert heralds a 19th century practice where the unavoidable limits of the perception and the instrument are taken into account, mostly in mathematical-statistical way. This shift takes place as part of a more general evolution, viz. the standardization of experimental life and mathematization of experimental physics in the surrounding of the Ecole Polytechnique and the growing internationalization of science (e.g., astronomy) at the beginning of the 19th century. Lambert is indeed part of this evolution. His mathematical background allows him to find new procedures to overcome difficulties arising in experiments, and as his involvement in the founding of the *Berliner Astronomisches Jahrbuch* and in a mathematical table project shows, Lambert was also a zealot of internationalization and standardization.46

This inscription of Lambert into a broader general epistemic evolution, although correct, fails to do Lambert's theory and practice of science truly justice. E.g., Lambert's heralding of statistical techniques obscures the fact that, deep down, his approach is incommensurable with later 19th century developments. As his former collaborator Johann Karl Schulze writes in an article published shortly after Lambert's death, Lambert's graphical "constructions" (for doing astronomy in this case) are most "ingenious" but few are so dextrous at executing them, therefore Schulze prefers "a long and troublesome calculation" (Schulze 1782, 332-333). This is indeed the direction the generation after Lambert would choose. Equally, his careful, detailed but involved theory of science would be dismissed by the next generation of philosophers (especially by Hegel in his *Wissenschaft der Logik* 1812-1816). Lambert's *Organon* is still deeply rooted in a scientific tradition associated with craftmanship (e.g., the constructions) and in a logical and semantic framework in the line of Christian Wolff's philosophy. Perhaps exactly in these antiquated roots lies much of the uniqueness and constistency of Lambert's approach. To achieve a faithful mapping of the things in the real world and the concepts in intellectual world lies at the heart of Wolff's theory of knowledge and of Lambert's too. Seeing, however, the inadequacies of Wolff's simple logic and mathematics to assure the psychological reductions occurring in that symbolic thinking that is supposed to link up real and intellectual world (cfr. footnote 29), Lambert supplements it with various stratagems and heuristics such as probabilistic logic, visualizations etc. These retain a fragmentary and transitional character , being part of a "tool kit" of the mind, and because, ultimately, a mathematical expression is the goal, but they indeed announce a new awareness of the world and its phenomena and a new way of interacting with it, acknowledging that feedback between nature and its apprehension is inevitable.

1 Original: “Nach diesen vier Fragen entstehen auch vier Wissenschaften, deren sich der menschliche Verstand als eben so vieler *Mittel* und *Werkzeuge* bedienen muß, wenn er mit Bewußtsein das Wahre als wahr erkennen, vortragen und von Irrtum und Schein unterscheiden will.” The four sciences in question (also the four parts of Lambert’s *Neues Organon*) are: Dianoiologie, the laws of thinking; Alethiologie, the difference between truth and error; Semiotik, the doctrine of language and signs; Phänomenologie, the doctrine of appearance.

2 In the following we will write references with Dian., Aleth., Sem., Phän. for the four parts of the *Neues Organon*, and Arch. for the *Anlage zur Architectonic* with the corresponding paragraph number. E.g., Sem. §69 refers to paragraph 69 of the 3rd part, Semiotik, of the *Organon*. This accords with Lambert’s own use of referring to these works and helps modern readers to find the correct passage in the different editions that exist of Lambert’s *Organon*.

3 Original: “Die Routine ist ebenfalls verschieden. *Wolf* abstrahirte gern. *Baumgarten* suchte die abstracten Begriffe auf die Arten anzuwenden, um neue Arten zu finden. [...] *Meier* gebraucht seine Topic. *Euler* calculirt. Dan. *Bernouilli* nimmt gern sinnliche Bilder zu Hülfe. *Muschenbroeck* experimentirt ohne Theorie. Andere nehmen gern Hypothesen an. Jeder hat einen besondern Favoritleitfaden.”

4 Philosophical interpretations of this part of Lambert’s work, neglecting its applications and mathematical content, can be found in (Berka 1973 and Basso 1999, 170–172).

5 This is the topical table published in the Nova Acta Eruditorum (Lambert 1768) and reprinted in (Lambert 1782 & 1787, I, 267-294).

6 Original: “Er schrieb alles, was ihm darüber einfiel, auf; ordnete diese Sätze nach den gewöhnlichen logischen Regeln; suchte sodann die Lücken auszufüllen; schlug hernach andere Bücher, besonders Wörterbücher nach, um die ganze Ausdehnung des Begriffs zu haben, und durchgieng endlich die Materie nach einer logischen Tabelle, die er in den Leipziger Akten herausgegeben.“ ([Lichtenberg] 1778, 275). The same `algorithm' but in more detail can be found in a letter to Kant (Lambert 1781-1787, I, 345–346).

7 Original: “Die analytische Methode gleicht einem Wege nach einer Anhöhe, auf welcher man die ganze Gegend übersehen kann.”

8 The lucky ideas (“glückliche Einfälle”) are repeatedly discussed in Lambert's fragments, see (Lambert 1782 & 1787, I, 456-461; II, 198-138). Traces, symptoms, side-roads, detours and lucky occasions are discussed in fragments XXIX, XXVI & XXXIX, XXXIV, XXXV and XXIII respectively (Lambert 1782 & 1787, I). The importance of tricks, fragment LIII, is conceived as an afterthought to the fragment on lucky ideas (Lambert 1782 & 1787, II, 166).

9 Murhard (1798–1799, II, 727–928) gives an overview, with long quotes, of all publications concerning hygrometry. Cfr. also (Feldman 1990, note 36).

10 See (Feldman 1990, 143–144) and more recently (Golinski 2007). Whereas Feldman stresses more the quantifying aspect of late 18th century meteorology, Golinski contextualizes meteorologic instrumenting and recording within the broader cultural context of the Enlightenment, particularly as an interesting window on the relationship between man and his environment.

11 On the place of Lambert’s investigations in the history of hygrometry: For a contemporary account, see (Murhard 1798–1799, 776–813); for a modern account (Feldman 1983, Chapter 4).

12 Original: “Ces expériences faites à dessein, & dans des circonstances choisies, sont autant de problemes que nous proposons à la Nature. [...] Elle répond précisément, non à ce que nous croyons demander, mais á ce que nous demandons en effet. A moins donc que d’être éludés & trompés dans notre attente, il faut s’assurer rigoureusement des conditions que le probleme présuppose, afin de choisir les circonstances, & d’y adapter l’expérience qu’on veut faire.”

13 Original: “La Physique expérimentale se rend absolument nécessaire par tout où il n’y a pas moyen de voir le mécanisme par lequel la Nature opere [...] on y joint le calcul, on y applique les principes de

la Mécanique, là où ce mécanisme se dévélope assez pour être vu, ou qu'il est assez simple pour être conçu."

14 Original: "Le calcul y fournit la précision & l'universalité. L'expérience vérifie l'une & l'autre, & découvre chaque circonstance omise, ou faussement admise. En négligeant le calcul, & la théorie qui lui sert de base, on fait les expériences sans choix & sans dessein. En négligeant les expériences, on court risque de donner dans la chimere, & de produire des calculs applicables à toute autre Monde, qu'à celui où nous sommes."

15 Original: "Alle coordinirte Ideen in den Wissenschaften hängen durch umgekehrte Sätze zusammen."

16 Original: "Wenn eine nach Regeln gemachte Sache gegeben, die Regeln zu finden, nach denen sie gemacht worden, oder hätte können gemacht werden." The quoted phrase occurs in a discussion on cryptography and, according to Lambert, turns the problem of decyphering a message into a very general analytical problem. Indeed, the formulation comes close to something like black-box analysis, viz. deriving or (re)constructing the internal structure of a machine/animal on the sole basis of its in- and output (resp. its behaviour), see e.g. (Moore 1956). Interestingly, black-box analysis also grew out of the problem of secret communications in World War II.

17 For another application of the same concepts, consult (Lambert 1770/1772).

18 Original: "Il semble que pour rendre la Météorologie plus scientifique qu'elle ne l'est, il faudroit imiter les Astronomes, qui, sans s'arrêter d'abord à toutes les minuties, commencent par établir des loix générales & les mouvemens moyens. [...] Que n'en est-il de même de la Météorologie? Il est très sûr qu'elle a des loix générales, & qu'il y entre un grand nombre de phénomenes périodiques. Mais á peine peut-on encore deviner ces derniers. C'est peu de chose que les observations qu'on a faites jusqu'à présent, entre lesquelles il n'y a point de liaison."

19 Lambert here pursues and extends an idea of Musschenbroek (Geurts and van Bigelen 1983, 31-52). Of course, weather diaries had been kept since the beginning of the 18th century, but they rather meant to record extreme events than to keep track of a continuous phenomenon, see (Jankovic 2000).

20 This is not an isolated case. In mathematics, periods and periodicity played a similar role around 1800 to turn a data-driven number theory into a modern theory of structures in the hands of Gauss and others. Compare with (Bullynck 2009a) and (Goldstein and Schappacher 2007).

21 Original: "Il n'est pas nécessaire d'expliquer ce que c'est que l'humidité. On n'a qu'à passer par un brouillard pour s'en appercevoir; car c'est une humidité qui tombe sous la vue & le tact. On la voit encore dans les vapeurs qui s'élevent des fluides bouillonans. Elle se rend aussi visible, quand pendant l'hyver elle s'arrache aux fenêtres, ou qu'elle couvre les objets exposés à l'air en forme de brume, ou enfin lorsqu'elle se présente en forme de rosée, qui couvre la surface chevelue des plantes d'une infinité de petites gouttes. Enfin elle s'attache visiblement aux corps vitrés, métalliques &c. lorsque pendant l'hyver on les transporte du froid dans des chambres chauffées. En tout cela il n'y rien qui ne soit connu de tout le monde."

22 For a good presentation and analysis of Lambert's views on language, see (Ungeheuer 1990).

23 Procedures and hints to achieve reduction of the "hypothetical" within language are given Sem. § 329-352.

24 Original: "Diese [Begriffe und Merkmale] werden nun nicht bloß zusammengesetzt oder nur aufgehäuft, sondern damit gleichsam multiplicirt, weil das, was der abstracte Begriff vorstellete, noch neue Eigenschaften bekömmt."

25 This was an important issue for Lambert: "The amount of artificial words, especially in cases where the thing at issue cannot be readily presented, becomes a burden for the memory and not all like to learn them and keep them in mind without changing their meanings." (Arch., §24) (Original: "Denn die Menge der Kunstwörter, zumal wo man die Sache nicht vorlegen kann, wird dem Gedächtnisse zur Last, und nicht jeder bequemt sich gern, sie alle zu lernen, und mit unveränderter Bedeutung im Sinne

zu behalten.")
26 Original: "Le degré d'humidité de l'air c'est la masse ou encore le poids de toutes les particules aqueuses, qui nagent dans un certain volume p.ex. dans un pied cube d'air. Voilà donc à quoi doit se réduire le langage des hygrometres."
27 Original: "Tâchons donc de la [la humidité] poursuivre dans les principaux phénomenes qu'elle offre pour être évalués & mesurés. Commençons pour cet effet à la voir dans sa naissance."
28 For a history of visualization in science and Lambert's prominent early role in it, see (Tilling 1975 and Beniger and Robyn 1978). More on Lambert's graphical curve-fitting can be found in (Gray and Tilling 1978, 23–26). Laura Tilling analyzes part of Lambert's work, the theoretical work and the application in magnetism and pyrometry in the unpublished (Tilling 1973, Ch. III, IV), Zeno Swijtink also announced a book project on Lambert's graphs and methods that never materialized. Lambert's own theoretical treatment is in (Lambert 1765). The most extended discussion of curve fitting (the one applied here) is, however, found in the *Anlage zur Architectonic*, the 23rd chapter entitled 'Vorstellung der Größen durch Figuren' (Arch. §885–902). See (Bullynck 2008) for a detailed discussion with examples.
29 This important philosophical distinction between apprehension through figures and through signs goes back at least to Leibniz who introduced it in his "Meditationes de cognitione, veritate et ideis" (1684). For Leibniz, however, the *cognitio intuitiva* (cognition mediated often, though not exclusively through figures, or at least cognition seen and understood 'at a glance') was superior to *cognitio symbolica* (cognition through signs) as a mode of apprehension. Christian Wolff extended considerably on Leibniz's text, and devoted a large part of his *Psychologia Empirica* (1738) to this issue. Contrary to Leibniz, Wolff insisted on the fact that both modes of knowledge are on the same epistemological level, or at least that the *cognitio symbolica* could be transformed into *cognitio intuitiva* by psychological reductions, stressing time and again that symbolic cognition is of the foremost importance in science (algebra being the prime example).
30 Original: "Il seroit assez difficile d'assigner a priori une équation algébrique, qui satisfait à la courbe qu'offre la cinquieme Figure. [...] mais nous pourrons toujours indiquer les symptomes généraux, auxquels cette courbe doit satisfaire."
31 For Lambert's graphics see footnote 24, for Lambert's computational methods see (Sheynin 1970/1971a and 1970/1971b) and (Bullynck 2008).
32 Lambert's equation corresponds more or less to the modern simplified equation $dy/dx=-ky$ for the rate of evaporation. A more elaborate equation, taking into account all circumstances (air pressure, sporadic elements in the water ...) has been given by (Penman 1948).
33 Original: "Les baromètres, dès sa premiere invention, parla au moins un langage intelligible; le thermomètre ne le parla pas d'abord. Ce n'est qu'en 1714 que Fahrenheit remit à Mr. Wolf deux thermomètres correspondants, & encore aujourd'hui ce langage n'est que comparatif. [...] [on doit] considérer [les hygromètres] de plus près, pour apprendre à en connoître le langage, & à le rendre intelligible."
34 Original: "Il restoit encore à soumettre mes hygrometres à d'autres examens, qui devoient aboutir à en faire connoître le langage & les loix de leurs variations."
35 To explain and measure how much water the air contains, Lambert refers to his work on the speed of sound in humid air (Lambert 1768).
36 To be a little bit more accurate, Lambert remarks that the ratio of surface to volume of the sponges varies too much for each individual sponge. A solution, he suggests, would be to take large sponges where this ratio would be stabler. However, larger sponges have the disadvantage, that the interior of the sponge has no surface to evaporate. (Lambert 1769, 125-126)
37 This section confirms Hackmann's statement that in the 18th century concepts informed the making of an instrument and vice versa (Hackmann 1979). The statement should, however, be modified in this

sense that Lambert did not only see the necessity of providing a more general framework, both theoretically and practically, but even provided one as early as 1765.

38 More on Brander in (Brachner 1983, 15–28). Pictures of the hygrometers Brander constructed can be found in the same volume p. 258 and 260. Lambert had been in correspondence with Brander since 1765 and pursued it until his death in 1777. The correspondence was posthumously edited by Johann III Bernoulli as the fourth volume of *Lambert's deutscher gelehrter Briefwechsel*.

39 Original: "Ich wünschte diese Hygrometer gemein zu machen, und dann könnte die Abhandlung übersetzt werden." (Lambert 1781-1787, IV, 307)

40 Brander to Lambert (April 20, 1772): "wenn gleich die mehresten [Hygrometer] bey mittlerer Feuchtigkeit ziemlich genau harmoniren, so differiren sie doch öfters untereinander sehr in beyden Extremis der Trockenheit und Feuchtigkeit. Daher ich auf den Gedanken verfallen bin; man sollte sie nach einem einmal angenommenen Etalon durch alle Grad abgleichen und jene in diese reduciren; dadurch erhielte man durchgehends einerley Valor und würde auch manches tüchtiges Stück Saiten können beybehalten werden." (Lambert 1781-1787, V, 324)

41 Still, two years later, small variations often occurred. Lambert complained about the sometimes failing correspondence in his letters (Lambert 1781-1787, IV, 409).

42 Sagan lies between Frankfurt/Oder and Görlitz.

43 In (Bullynck 2008, 1 and 10) I called this kind of mathematico-mechanical and similar "submathematical" techniques "Archimedean" mathematics.

44 See the recent studies (Chang 2004, 17-23; 60-64) and (Hofmann 2006, 68-84) for an analysis of De Luc's work and its incription into a philosophy and practice of science.

45 This device, discussed at the end of the *Neues Organon,* is not used in the hygrometric studies. In short, if an investigation ends up in a variety of cases, Lambert uses his probabilistic logic to reduce the variety to one probabilistic proposition are a connected series of probabilistic propositions.

46 For Lambert's involvement in the astronomy journal see (Kokott 2002), for the mathematical table project (Bullynck 2009b, Parts 3 and 4).

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